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Our Field Testing Program*

By R. J. Borden

The extent of the decline in the number of replicated field tests which are now in progress on our plantations is somewhat discouraging to those of us who are charged with the application of scientific methods to studies of the everyday field operations, and with the determination of the relative efficiencies of different agricultural practices. The possible effects from such a reduction in field-test activity upon the future of our agricultural progress should receive our fullest consideration at this time.

We all know that labor-saving devices and techniques are of paramount importance in today's agriculture. There are many individual opinions but fewer facts to support some of the current field practices. A scientific analysis of the factors involved should provide facts now which will still be valuable after the war. This is not the time to "stand by."

It has been the policy of your Association to depend largely on the plantations for cooperative assistance in the field testing of problems which can only be satisfactorily studied through comparisons made in the fields. We believe that now, more than ever, there is a need for the continuance of this cooperation in our research, especially in connection with the everyday or ordinary field operations. How else, for instance, are we to get maximum returns from 32–8560 until we know what gaps in stand it can tolerate without replanting, its capability of enduring variations from a complete weed control, its nitrogen requirements, its maximum irrigation interval and how long it can be "dried off" before harvest, its optimum age for harvest, and what interval it will stand between cutting and milling without severe loss through deterioration? How else are we to know whether some of the changes we have been forced to make in our field practices during the

* As presented at the 63rd Annual Meeting of the H.S.P.A. on December 6, 1943.

past two years are efficient enough to warrant their maintenance after the war. It will be very easy to get into some bad agricultural habits during these trying days—habits which we may tend to continue after the war, and because we have made so many changes it is going to be very difficult to differentiate between those procedures which are actually efficient and those which are mistakes, unless we get busy now and get the facts. Furthermore, it is not at all unlikely that still more changes in some of our field practices might be made, with resultant savings in man-days of labor and without causing a reduction in sugar yields. I would like to elaborate just a bit along these lines, in hopes that someone of you will find a thought worth further consideration that might be applicable to at least some part of your plantation area. But first let me refresh your memories just a little.

Not so many years ago plantations on the island of Hawaii bought and applied many tons of lime to their fields. Repeated tests by field experiments proved that this lime had no beneficial effects on sugar yields, and today there is practically no liming of acid soils being done.

The ineffectiveness of "cutting back" was proved in your field experiments, and this field operation which was quite common at one time has been dropped. The same can be said of the old practice of stripping.

Hilling up and off barring were common field practices until the field tests continued to show that they did not increase sugar yields and, though perhaps not quite as common, we find considerably less subsoiling being done today because, except for a few abnormal areas, the experimental evidence secured from field tests has not shown this operation to be essential.

Ten years ago I made a survey of fertilizer practices which showed medium-to-heavy applications of phosphates being made to both plant and ratoon fields. Repeated field tests have in general failed to show a profitable response to phosphate on those old lands which have been continually in cane since then, and the amounts of this plant food that are being applied today have been greatly reduced and in many cases actually stopped.

Finally, it wasn't so long ago that we spent a lot of time and money to return filter cake to our fields, and it is my guess that we would still be doing this if the experimental evidence had not convinced us that we were not getting any more sugar and were having to harvest a lot more cane when we applied filter cake. So from an economical standpoint we are today disposing of our filter cake in the cheapest way possible.

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But to proceed: Let's take a look at the way we are growing our 32–8560 and 32–1063, and the results say that we are doing a pretty good job of it too. But can we afford to rest on present results; can't we do a still better job? For instance: do we know what minimum amount of preparation is required for these new canes?

On irrigated lands, the deep plowing that is now done so that the cane lines will hold up through the following ratoons is not so essential since we have developed such efficient line reshapers to fix up ratoon fields. And then too, our present harvesting methods break down these lines to such an extent that it is necessary to build up new lines for ratoons before we can get the water on.

On many of the unirrigated lands, I still wonder why we plow at all. If plowing is done for the purpose of loosening a compacted soil, letting in air and water, then we need to know that sugar yields would be reduced if we did not do such plowing. If it is for the purpose of deepening the soil to allow for an extended root zone, then a sub-surface implement will do an adequate job. If it is for the purpose of burying surface trash and stubble, then we need to know the effects on the nitrogen economy which buried trash will have—for in the decomposition of this organic material the soil organisms are going to use up some of the available nitrogen. If it is to bury the weed seed, then we should give thought to ways and means of destroying the weed seed as it is left on or near the surface of the soil instead of burying it deeply, and then having it come to life whenever we turn over the soil again.

Then we have the question of "What width of row is desirable for these new canes"? If we were to increase the distance between cane rows from 4½ to 5½, or from 5 to 6 feet we would have a good quarter of a mile less of cane rows on each acre. This would take less seed to plant, fewer lines to irrigate, to fertilize, and to cultivate or spray. You can easily see the possible savings in man-days needed to operate such acres—and right here is a possible labor-saving device.

I can already sense your objections to this suggestion. You will say that the wider rows will be slower to close in and so will give you still more weeds to fight. This may be true as far as the interline is concerned in plant fields, but since stands of 32–8560 tend to be thicker and more dense within the cane row when they get the added light which wider rows will give them, there should be even fewer weeds in the cane line where it is always more difficult to control them. And the extra growth between the rows should not add much to the actual weed nuisance.

Your objections on the basis that present equipment is standardized, is also overruled, for we have changed and will continue to change our equipment to make it do the job we want done.

But, will yields be adversely affected by these wider rows? Only the replicated field test can answer this. So let's get the facts before we start raising too many objections.

Next comes the ever present problem of weed control. No field operation is getting more attention these days. It's a problem that has always been with us, and it probably will always bother us to a greater or less degree. The chances are very remote that we can eliminate weeds in plantation-scale agriculture—hence our efforts will continue to be in the direction of reducing their detrimental effects by using the cheapest methods we can devise for an effective control.

That great progress has been made in weed control is not denied, but we must go further, for there are still too many man-days for hand hoeing being charged against our cost of production. So we ask this question: What *degree* of weed control is necessary in our 32–8560 and 32–1063 fields? At present we find great differences in this respect; at one place, control is started while the weeds are still in their cotyledon or not beyond their four-leaf stage; at another place the weeds are not touched until they reach their seeding stage. At many places it is still the practice to put in a final weeding just before the cane goes down. We are still not convinced that this final weeding is an essential one in 32–8560 fields, unless of course the weeds are of the viney types or climbers like honohono, hilahila, etc.;

for we believe that if the weeds are controlled sufficiently early to prevent them from shutting light away from the seed bed or ratoon stubble, then the weed nuisance, which is closely tied up with the density of weed growth, will be relatively ineffective on final sugar yields. Furthermore, when the stalks get their growing points above the common annuals and grasses, the weeds will have very little effect on subsequent cane growth of these new fast-growing varieties. We have the results from some of our skirmish tests to support this viewpoint. Thus, weeds starting with plant cane which were *not controlled at all* reduced the yield of 12-month cane by more than 70 per cent. When weed control was neglected for the first six weeks, the loss averaged 45 per cent even though full control was maintained thereafter. When no weeds were allowed to grow during the first six weeks, but weed growth thereafter was not controlled, the loss was only 25 per cent. Where there were no weeds allowed to develop in the first six weeks, and a weed crop which started then was brought under control six weeks later there was no loss in cane or sugar yield from 31–1389 cane. We recognize that these results were obtained in pot cultures and that the same degree of loss might not occur in field practice, but we *do* believe that they indicate the direction our weed control efforts should take, i.e., get the weeds early, and if they do get out of hand after the cane is waist high, take your loss and use your labor on fields with younger cane where it will bring better returns. All this needs proof in the fields however, and the only way to get it is through the field experiment.

Another thing, excepting the climbing weed types, the greatest damage done to a crop of cane by weeds is probably done before the weeds have matured, and this damage is chiefly the result of shading and thus limiting or preventing the stooling. If you fear that the weeds have robbed the cane of nitrogen, and they *will* get some of it, this can quite easily be returned with an application of fertilizer carrying 20 to 30 pounds nitrogen per acre.

In connection with this discussion of weed control, I must mention the recent practice of sub-surface fertilization, which among other virtues places the fertilizer below the root-feeding zones of most of the surface-feeding weed roots, but still not out of reach of the rapidly developing crop roots. In our more common practice of surface application of soluble fertilizers, we make it too easy for the weeds to get their food, and they take full advantage of our generosity. By putting the first fertilizer application well down under the seed, or deep in the subsoil groove alongside ratoon stubble, it will be positionally unavailable to most of the weeds, but the cane roots will reach it quickly, and cane growth will be stimulated and pushed right ahead of the weed growth.

Are you afraid that it will be lost, if it is placed too deep; that it will be leached too far down? We have tried rather unsuccessfully to leach ammonium sulphate below the 6-to-12-inch soil levels, even on acid soils. Although we *can* leach a nitrate nitrogen through many of our soils, in actual usage we probably do not do so, for if we did, we would find a difference in the efficiences of nitrate and ammonia nitrogens—and we don't find this difference. Hence even though a nitrate form of nitrogen can be moved downward by soil water, either from heavy rainfall or heavy irrigations, the fact remains that it is probably not actually lost to the cane crop. Isn't this suggested sub-surface fertilization worthy of your attention in field tests, since we don't know what its effect might be on sugar yields?

Next, how about a practice of alternate row cultivation? Under conditions of extreme labor shortage, some means must be found to spread the available labor over as many essential field operations as possible. The use of a practice of alternate row cultivation for 32–8560 fields occurs to us as one which might be studied for its effect on final yields. Thus on irrigated lands, weed control operations would start with a broadcast spraying. Thereafter, mechanical cultivation or knapsack spraying would be confined to alternate rows, keeping one row-middle free of weeds until the crop has established its stand. Fertilizer would be placed in the center of this clean row-middle, and should feed the two adjacent lines of cane. Naturally this practice could not be used on fields where honohono and climbing weed types persist.

On the irrigated lands one might also consider putting fertilizer on alternate cane rows. Our studies of border effect in field tests have suggested that this might be done without a very serious reduction in yields of the alternate unfertilized row. Furthermore, on soils which have good lateral seepage, we might irrigate only every other line, and alternate the irrigated row in every other round; such a procedure might be well adapted especially to hilled-up ratoon fields. If it could be proved that such methods did not reduce sugar yields, it goes without saying that they would increase man-day performance and grow cheaper sugar. However, they are not procedures to be adopted without checking in replicated field tests on such of your fields where they may have a reasonable chance of succeeding.

Then we have the nitrogen problem. Questionnaires returned to the Genetics department recently recorded an overwhelming opinion that 32–8560 needs less nitrogen than other varieties. How do we know? I think so too, but honestly, do we have the facts? I have a strong suspicion that we can get better quality from 32–8560 which is scheduled for fall harvesting if we hold its nitrogen supply down —perhaps to not more than 100 or 125 pounds—and put it on early, for there is less and less evidence that there is anything to be gained from holding back some nitrogen for a second-season application (at 11 or 12 months). I might go even further and ask "why can't we apply *all* of the nitrogen in one or at most in two applications? Are we afraid that it will be leached away if the applications are too large?" It may be that we have become unnecessarily concerned about the loss of soluble nitrogen fertilizers by leaching. All right then, why not a single fertilizer application located 8 or 10 inches below the surface when the crop is started? Here's a labor-saving idea, but will it decrease the sugar yields? Let's get the proof!

Should we plan now to grow only plant crops? Look for a minute at these figures which we have taken from some of your actual field records:

	Tons sugar per acre per month (TSAM)		
Field	Plant crop	1st ratoon	2nd ratoon
A-2	.54	.44	.31
A-4	.50	.35	.33
2-B	.60	.50	.42
9-A	.62	.53	.37
9-B	.56	.34	.36
2-A	.58	.51	.40
0-7	.66	.54	.49

I have many more just like them and your field records will show you similar ones. What do they mean? From field data recently submitted to the Genetics

department we have found this same sort of decline in TSAM from 32–8560 first ratoons. For example, 19 out of 22 fields reported, showed an average loss of .08 TSAM for the first ratoon over the plant crop, with 16 of these fields showing a loss for ratoons of more than one ton of sugar per acre. In these same fields, during their previous cycle with the variety that 32–8560 has replaced, the corresponding average loss for the first ratoon over the plant crop was .04 TSAM, so we have little reason to believe, at this time, that the decline in ratoons of 32–8560 will be materially different from that of former varieties.

At a loss of one ton of sugar per acre, we have the equivalent of a loss of about $40.00 before harvesting. Therefore, if it costs less than $40.00 an acre to bring plant crops to maturity than it does to mature ratoon crops—and I am sure that there are many fields where this would be true—then it can be quite uneconomical to grow ratoons on such fields. And if only plant crops were to be grown, there are many modifications of our field practices as now used that could be made which would still further reduce the cost of plant crops. Finally, in those cases where man-day requirements are apt to be lower in plant fields than in ratoons, such benefits will be gratefully accepted too.

I could continue to ask questions like these; questions that we frequently ask ourselves, and for which we do not have reliable answers; answers that would be valuable right now if we had them. We won't get them by a policy of dropping experimental work "for the duration." We won't be fully ready for the post-war competition with South American sugar if we put off our testing of these problems until the war is over. We need a re-evaluation of the field experiment today, for our cooperative field research has almost come to a stop. Won't you give it its share of your labor and attention, and help us to help you get the facts?

Elongation of Grain in Low-grade Massecuites

Compiled by W. L. McCleery

The long-recommended size of low-grade massecuite grain, boiled from normal quality material, has been a length of from 0.25 to 0.35 mm. when ready for the crystallizer. The usual width of such grain is about from 0.10 to 0.15 mm. At a few factories the width is proportionately larger and but slightly less than the length. An even grain, within these dimensions, is the minimum size that will purge well in the centrifugals and presents a maximum of crystal surface for the rapid reduction of mother liquor purity, without danger of forming false grain.

It has been noted for a long time, at many factories, that there are periods, usually of short duration, when the grain elongates without increasing in width, *i.e.*, grows only in length, and usually very slowly at that, so that the final dimensions may be only 0.05 mm. or less in width by perhaps 1.00 mm. long. This needle-shaped grain does not exhaust the molasses, frequently breaks up in the pan and the crystallizers and always tends to clog the screens in the centrifugals. Such strikes usually have to be finished at low density and the result is that the purity of the final molasses is high and the quality of remelt sugar is poor in the majority of cases.

Recently the California and Hawaiian Sugar Refinery staff reported that they were having trouble with a more or less similar type of grain in their second and third remelt strikes.

We have long known that periods of needle grain in low-grade massecuite have been associated with grinding soured cane resulting from any one of a number of causes; that in spite of any modifications in process procedure, very little could be done about it in the factory and that it served as a direct indicator that there were irregularities in the field or in the harvesting procedure.

We have rapidly changed cane varieties and harvesting methods in recent years, and had an acute shortage of plantation labor since some time "before Pearl Harbor," and as C. & H. Refinery was having trouble with its low-grade material, it was thought advisable to make a survey. Letters were sent to the manager of each factory asking that a member of their staff give us their experiences and opinions concerning needle grain. The letters contained a list of 23 questions covering various phases of the problem, particularly toward obtaining opinions as to causes, prevalence, and extent of difficulties encountered, the remedies tried and results. All but two factories of the 34 gave us complete reports. The questions and summary of the answers are listed below.

1. Is slow-boiling low-grade massecuite usually accompanied by long so-called needle-shaped grain?

The majority opinion is that slow boiling is not necessarily accompanied by the formation of needle grain.

2. In reverse does this long grain always boil and grow slowly?

The true needle-shaped grain nearly always grows slowly and the massecuite is classed as slow boiling.

3. *Possible Causes of Long Grain:* Does long grain come from poor clarification?

Poor juice clarification, as such, is not considered an indicator of needle grain in final massecuite. See, however, question No. 14 concerning honohono grass.

4. From certain cane varieties? 5. From certain field areas? 6. If from certain fields, are these situated so that harvesting is slower than normal? 7. From overage cane?

The answers to these questions were generally *no*. However, there is a firm opinion held by some that certain varieties, especially under makai land conditions, do not carry over well to the time of harvest. Certain mauka lands have also been mentioned. The explanation given is that many of the older or primary stalks die and the juice becomes sour or that souring is induced by cane borers working in stalks that are wholly or partially dead. Soured cane from any cause is considered to be the principal cause of needle grain.

8. Sour cane, from accidental fires? 9. From cane burned or harvested with too long an interval before grinding in dry weather? 10. From delayed grinding after burning or cutting, due to wet weather?

The opinion is almost unanimous that the amount of souring, under any of these conditions, is a reliable indicator of the severity of trouble that will result from needle grain. Several reports mentioned that souring is accelerated by wet weather after harvesting, particularly so by alternate periods of showers and hot sunshine.

11. From untopped cane? 12. From mechanically harvested cane?

Neither untopped cane nor mechanically harvested cane, as such, is thought to be a cause of needle grain. Mechanically harvested cane, however, has a great many stalks that are crushed, split and broken that will sour very readily, hence should be ground more quickly than cane harvested in the old manner.

13. From trashy cane with much field soil? 14. From trashy cane containing weeds and grasses?

The opinions on these two questions were fairly evenly divided. There were several replies which emphasized that decomposed field trash was a contributing factor. Several others reported that cane containing large amounts of honohono grass when ground gave poor clarification and was a cause of needle grain. We know that juice expressed from honohono grass alone does not clarify by any of the usual methods.

15. Is flumed cane with most of the soil removed less troublesome than non-flumed?

Answers from several of the factories grinding flumed cane indicate that fluming is an advantage in that dead cane is (partially) rejected by the men at the flumes.

16. Has juice purity, high or low ash or high or low glucose any apparent affect?

The analysis of the juice is not an indicator, except that it may reflect decomposition or souring as shown by low purity or high glucose. An unripe cane juice of 80 purity will not give the trouble that juice from ripe cane of 86 will, if it has soured to 80 purity.

17. Rough percentage of the days of crop year when long grain is bothersome?

About 50 per cent of the answers did not give an estimate, yet many of these stated that they were bothered by needle grain but had no definite data. The figures from 15 factories giving percentage estimates ranged from 3 to 40 per cent as follows: 25, 10, 15, 20, 40, 4, 5, 30, 13, 5, 20, 12, 3, 8, with an average of 15 per cent. The factories reporting high figures were Wailuku 30, Onomea 25, Kaiwiki 20, Paauhau 40, and Kilauea "not over 20 per cent." Five factories reported no needle grain or that it gave no trouble: H. C. & S., Waiakea, Hakalau, Hamakua and Lihue.

18. Is purging time of low-grade affected?

All factories reported slower purging massecuites, except the 5 who reported "no trouble."

19. Purity of low-grade sugar lower, by how much?

Twenty-two factories reported that sugar purities were reduced from 3 to 11 points when purging needle grain. The average is 6.0 points.

20. Purity of final molasses higher and by how much, during bad periods?

Twenty-four factories gave figures ranging from 1 to 6 points higher, with an average of 4.0.

21. Has any treatment of "B" molasses by soda, lime or otherwise, or modification in clarification procedure helped?

The majority report that no treatment tried has been effective. A few report that soda ash, added to the B molasses or introduced in the pan before graining, improves the boiling. One reports that running an "acid house" helps and another "reduced the pH." Kohala factory obtains "freer boiling and faster graining massecuites by adding soda ash to the clear juice from the secondary Dorr before it goes to the primary Dorr." Pioneer states that "if the juice is partly neutralized with soda before liming it will help slightly." Oahu and Ewa factories do not lime sour juices to the usual pH, to avoid using an excessive *amount* of lime. They reduce lime salts and build up the pH of the clarified juice by substituting soda ash for part of the lime.

22. Does long grain appear with no apparent cause?

Nearly all have very firm opinions as to the cause, *i.e.*, deteriorated juice in the cane, either before or after burning, or after harvesting. Grinding large amounts of decomposed leaves and "dead" cane are thought by some to be strong contributing factors.

23. Does long grain give more trouble now than 5 to 7 years ago?

The majority believe that they are now having more trouble than formerly. More cane is being damaged which makes it subject to rapid fermentation. Paauhau factory reports less trouble "due probably to a change in varieties" that carry over better.

Sidelights

Many factories submitted some very interesting remarks of which the following are a few excerpts:

Oahu:

Many years ago at the Oahu Sugar Company we came to the conclusion that sour cane and excessive trash were the cause of long-grain crystals. This contention was borne out by the fact that the long crystal invariably appeared in the pans after a rainy spell when field burns were poor, or the harvesting crews were unable to bring in the cut or burned cane on schedule, resulting in a high proportion of sour cane.

With the present harvesting methods where the cane is . . . [damaged], there is always present a small amount of sour cane. Mechanical harvesting is responsible for this but, with reasonably good field burns, this condition need not be serious providing the cane reaches the factory . . . [quickly].

Last year and the present year especially are very abnormal years . . . labor difficulties have thrown harvesting schedules all out of line, with the result that fields are overage at time of harvest. Two important factors enter the picture here and, unfortunately, both are equally bad. We have an excessive amount of dead cane and a high percentage of immature suckers entering the factory. Taken together, they both tend toward higher total lime in the mixed juice which our pH control does not indicate. Overliming, plus the non-sugars necessarily introduced by the above cane conditions, are the chief causes of slow boiling. Soil particles carried over in the clarified juice will likewise slow up boiling, but this is purely a question of fouled-up heating surfaces.

Honolulu:

1. During the 3 weeks we ran the refinery alone in August 1943 we had long grain for the total period.

2. In order to dry massecuites with long grain it is necessary to dilute the low-grade massecuite.

3. This month, when grinding cane from Waipahu which was 25 months old and hadn't been irrigated for almost a year, we had long grain and at the same time purities were low.

Ewa:

There are four different shaped crystals common in low-grade. They are as follows: 1. The square crystal. 2. The crystal with two corners off. 3. The rectangular crystal. 4. The triangular crystal.

The first two crystals are common at Ewa, with the square crystal holding the edge, and are the two easiest crystals to work with.

The rectangular and triangular crystals usually appear when the cane has become too dry or has become deteriorated. These crystals are hard to work with, the massecuite in both high- and low-grade strikes bôils slowly, and great care has to be exercised to keep out false grain. The latter of these two crystals is usually accompanied in the massecuite with an abundance of lime salts. The pan drop from massecuite to molasses is not normal when either of the above types of crystal are present, and it is practically impossible to approach anywhere near the expected final molasses gravity purity.

Waialua:

At no time during the 1943 season did we get real needle grain but very often we did get grain about 3 to 4 times as long as wide. Our experience is that only sour juice will produce long grain. The sourer the juice the longer the grain.

Maui:

We believe long grain to be due to damaged cane, either in growth, as by exposure to salt spray, drying out, insects or fungus, etc., or to damage afterward, as burning too long before harvesting, delay in grinding, etc.

Pioneer:

With us, at least, the conditions which produce needle grain are always brought about by some abnormal field situation. Deterioration of the cane, due to age; sour cane which sometimes occurs when weather interferes with loading; machine cane badly mangled which has bled badly and become sour; and too long a time between burning and grinding.

Kilauea:

As a rule we encounter excessive long grain when we are grinding trashy and grassy cane from poorly burned fields. At times we get long grain for no apparent reason, but on checking we usually find that the cause is from cane that has been cut for about 24 hours and subjected to intermittent showers and hot sunshine. On the other hand cane in the same field may be 24 hours older and not cause long grain if the weather is constant. It seems that dampness and heat have a tendency to increase the rapidity of inversion.

Paauhau:

We have found it [needle grain] due to deteriorated cane or "dead" trash.

We have observed needle grain at this factory since 1930 and have found graining methods that produce "square" grain in other locations to be of no effect when handling deteriorated material. Our cleaning plant has been a help in that it removes most of the "dead" trash.

Our observations have been as follows:

1. Agitation of low-grade massecuites while boiling increases elongation of grain; consequently we do not start the mechanical circulator in our low-grade pan until it is about ⅓ full.

2. When the initial grain is well formed, it will elongate if the molasses boiled in is from poor quality cane; also, poorly formed initial grain may correct its form if good quality molasses is boiled in.

3. Increase of purity of graining charge aids at the beginning, but the purity of the completed strike determines the amount of elongation with a given material.

4. Low supersaturation boiling in early stages of strike and "closing" the strike by boiling on water does not affect final results.

5. The tendency in our case has been for needle grain to increase after about the first of August, when juices have passed their "peak" stage.

Hutchinson:

When boiling massecuite of high viscosity we find that long grain only appears when boiling low-purity syrup or molasses from sour cane, especially when grinding dirty sour cane containing tops and other field trash.

We have noticed that boiling conditions and grain quality improves when the period between cutting or harvesting and grinding is favorable, say 48 hours or less.

Pepeekeo:

Some observations noted on juices that produce needle grain:

Pan boiling time doubles. Always subject to the formation of a secondary mass of needle grain upon concentration of massecuite. Nearly impossible to wash out, as the original grain melts before the needle grain. In most cases washing increases the difficulty.

In seeding low-grade pans the grain first appears normal and square; upon concentration it becomes elongated. Further concentration brings out additional fine needle secondary grain. In a few rare cases it has been almost impossible to start a seed in a graining molasses.

Drying low-grade in some cases would be impossible except for excessive overheating of the massecuite. Greatest trouble is the molasses forming on the inside of the centrifugal basket. Sugar would be well dried behind a layer of molasses sometimes thicker than the layer of sugar.

The writer wishes to thank the managers for their cooperation and the factory staff members who prepared their very complete reports for us.

Cumulative Effects from Heavy Applications of Nitrogen Fertilizers

By R. J. Borden

Although different sources of nitrogen used in the fertilization of sugar cane on irrigated soils will have different cumulative effects on the pH of the soil, and may also affect the solubility of some soil minerals, it has not been convincingly proved, after ten years of excessively heavy applications, that cane or sugar yields are differentially influenced by these changes in the soil.

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Whenever a group of sugar cane agriculturists get into a discussion about the relative merits of ammoniacal and nitrate nitrogen fertilizers, and listen to the ammonium-sulphate advocate cite instances of actual loss of nitrate of soda nitrogen through leaching, and to the nitrate-of-soda advocate quote proof of conditions of practically soil sterility caused by the cumulative residual acidity from ammonium sulphate, some bright individual is always prepared to throw in the comment—"so what"! Thus it was, following just such a discussion in 1932, that J. A. Verret proposed that we set up a test* to determine the effect that continued heavy applications of different nitrogen fertilizers to an already acid soil would have upon cane yields and its quality and sugar recovery, since these were the important measurements that would have real meaning to the planters. Coincidentally a study of some of the effects which these large applications of fertilizer would have on soil and plant composition might supply data which would be useful in interpreting any yield differences which would be secured. It is ten years since the original crop was planted and the results from the nine crops harvested during this first ten-year period can now be summarized.

The Plan

The soil selected was a residual yellow-brown silty loam from Manoa, Field 22, with an excellent granular structure and organic matter content which makes it well-drained. A composite field sample analyzed by our Chemistry department was reported to have the following composition:

	1% Citric Soluble				Water Soluble				
pH	SiO_2	CaO	K_2O	P_2O_5	SO_3	Na	Al	Cl	Fe
5.3	.183	.037	.009	.011	.0025	.0025	Trace	.009	.011

A large stock of this soil was thoroughly mixed and then transferred to large 2′x2′x2′ concrete pots (Fig. 1), the insides of which had been well coated with asphalt. In filling these pots the soil in the lower halves was firmly tamped before the upper layers were put in, thus the soil conditions in these containers were made more comparable with those of the field. Careful estimates, and volume weights made later on, place the amount of soil per pot at approximately 420 pounds.

* Project A-105—No. 33.

Although the citric-soluble soil analyses had indicated no real deficiency in phosphate, a heavy application of superphosphate was made under the seed at time of planting.

Fig. 1. The tenth crop of sugar cane (now 31–1389 third ratoons) at age of 5 weeks, growing in the 2′x2′x2′ concrete containers which were originally filled with Manoa soil in 1933 and to which nitrogen from different sources (see text) has subsequently been applied in an amount equivalent to a total of 9,000 pounds of N per acre.

Cuttings of the cane variety POJ 36, carrying eight good eyes, were planted on June 5, 1933 and, as soon as a good selection could be made, the stand was thinned to four primary stalks per pot; thereafter no attempt was made to control the stooling. Similarly, for each ratoon crop grown, we have attempted only to see that the crops were started off with comparable stands in all pots.

The cane crops in these large containers have at all times received adequate and sometimes excessive irrigation, and during periods of heavy rainfall the excess waters with whatever solutes they contained have been carried away through the drainage holes two feet below the surface of the soil in the pots. Since the pots were set up at Makiki, it has been necessary to use Makiki tap water for irrigation and this, like most of the pump waters used for irrigating sugar cane lands, has an alkaline reaction (pH 8.1–8.3) which probably has had some effect on the soil reaction.

Fertilization of each crop was specifically planned so that excessively large amounts of three different nitrogen fertilizers would be applied to the relatively small volume of soil in each pot; the basic idea was to learn as quickly as possible whether such large amounts would eventually ruin this soil for satisfactory sugar cane growth. Hence it was planned to give each pot nitrogen at the rate of 1000 pounds per acre for each crop to be grown. Three sources of nitrogen were chosen —ammonium sulphate, nitrate of soda, and urea. In addition it was decided to check the results from ammonium sulphate when the total amount for each crop was given

in a single vs. several applications. Thus four treatments were installed and are identified as follows:

Treatment identity	Source of N	Number of applications per crop
A	Ammonium sulphate	In one application at 4 to 6 weeks.
B	Ammonium sulphate	In 4 applications at 2-month intervals. (*Note:* After the third crop this was changed to 5 applications at 6-week intervals.)
C	Nitrate of soda	
D	Urea	

All pots received identical and adequate amounts of both potash and phosphate for each crop grown.

The Results

In Table I we give some of the pertinent data taken from the nine crop "logs."

TABLE I

CROP HISTORIES

Crop year	Variety	Crop	Planted	Harvested	Age (mos.)	Fertilization grams per pot N	P_2O_5	K_2O
1934	POJ 36	Plant	6/5/33	11/15/34	17.3	42	42	42
1935	POJ 36	1st ratoon	11/16/34	11/26/35	13.3	42	21	21
1937	POJ 36	2nd ratoon	12/27/35	3/31/37	15.0	42	21	21
1938	POJ 36	3rd ratoon	4/9/37	4/21/38	12.3	42	21	61
1939	POJ 36	4th ratoon	4/22/38	4/18/39	12.0	42	21	61
1940	POJ 36	5th ratoon	4/19/39	5/7/40	12.6	42	20	100
1941*	31–1389	Plant	6/17/40	7/2/41	12.5	42	20	100
1942	31–1389	1st ratoon	7/3/41	6/29/42	12.0	42	40	100
1943	31–1389	2nd ratoon	6/30/42	6/28/43	12.0	42	40	100

* After the 1940 crop was harvested the old POJ 36 stubble was removed, the surface foot of soil was loosened up and turned over, and the pots replanted with the variety 31–1389 after only 6 weeks of fallow.

TABLE II

CANE AND SUGAR YIELDS

Crop year	Average pounds of cane — treatment A	B	C	D	Min. diff. req.	Average pounds of sugar — treatment A	B	C	D	Min. diff. req.
1934	52.8	55.6	51.9	49.6	4.4	7.44	7.99	7.35	7.33	ns
1935	35.8	40.4	41.0	37.8	ns	4.75	5.40	5.56	5.12	ns
1937	28.3	36.8	35.8	33.8	ns	3.62	4.56	4.74	4.58	ns
1938	21.6	32.4	32.0	26.4	3.9	2.94	4.27	4.29	3.54	.54
1939	28.4	33.3	33.8	31.1	ns	3.63	4.08	3.97	4.20	ns
1940	34.5	35.7	32.0	35.7	ns	4.91	4.10	3.83	4.19	ns
1941	71.3	63.0	64.1	56.9	8.0	10.78	8.78	9.18	8.55	1.13
1942	48.7	51.0	52.6	47.7	3.3	6.73	6.28	6.65	6.00	ns
1943	48.6	57.7	56.4	52.7	ns	7.38	7.90	7.66	7.35	ns
Total for 9 crops	370.0	405.9	399.6	371.7	—	52.18	53.36	53.23	50.86	—

ns = difference not significant.

Yields: In Table II a summary of the cane and sugar yields is shown. The crop figures are averages from four replicates, and where the treatment effects were statistically significant, the minimum difference required (for P at .05) is also given. These yield data show quite convincingly that (1) there has never been any significant difference in the effect on yields between ammonium sulphate and nitrate of soda (Treatments B and C); (2) although urea (D) has been slightly less effective than either nitrate of soda (C) or ammonium sulphate (B), this has not been true in all crop years; and (3) yield differences resulting from the use of the ammonium

sulphate in single (A) or in split (B) applications have not consistently proved the superiority of either practice.

The average cumulative yield of cane harvested from all treatments for this ten-year period was 387 pounds of cane per container. An equivalent field yield would depend upon how it is calculated, *e.g.*, (*a*) if based on the actual surface area of each pot (four square feet) the cumulative yields would be comparable with 2107 tons per acre or with twenty-one 100-ton crops; (*b*) if based on the actual weight of soil in each pot, it would amount to roughly 1150 tons per 2½ million pounds of soil, or to eleven 100-ton crops from an acre of soil one foot deep; and (*c*) if based on the maximum "feet of row" in the containers (two feet) and the assumption of 8712 feet of cane row in an acre in the field, the cumulative yield is 843 tons per acre or the equivalent of about eight 100-ton crops. Take your choice if you insist on a field equivalent!

TABLE III

CRUSHER JUICE COMPOSITION

Crop year	Yield per cent cane treatment A	B	C	D	Min. diff. req.	Per cent nitrogen (N) treatment A	B	C	D	Min. diff. req.
1934	14.08	14.38	14.18	14.75	ns	—	—	—	—	—
1935	13.28	13.34	13.54	13.49	ns	.015	.025	.028	.014	.008
1937	12.50	12.22	13.00	12.88	ns	.022	.026	.018	.016	.007
1938	13.58	13.15	13.40	13.32	ns	.015	.027	.020	.020	.003
1939	12.60	12.31	11.78	13.52	ns	.018	.029	.021	.019	ns
1940	14.26	11.52	12.03	11.72	1.77	.015	.032	.021	.022	.006
1941	15.16	13.95	14.34	15.04	.41	.012	.014	.015	.015	ns
1942	13.82	12.33	12.64	12.59	ns	.010	.016	.018	.018	.003
1943	15.16	13.67	13.56	13.94	.38	.011	.016	.015	.014	.004
Avg. for 9 crops	13.83	12.99	13.16	13.47	—	.013	.021	.017	.015	—

Crop year	% phosphoric acid (P_2O_5) treatment A	B	C	D	Min. diff. req.	% potash (K_2O) treatment A	B	C	D	Min. diff. req.
1934	—	—	—	—	—	—	—	—	—	—
1935	.011	.014	.013	.017	ns	.035	.038	.038	.053	.013
1937	.017	.015	.016	.016	ns	.030	.020	.020	.022	ns
1938	.021	.021	.023	.028	.005	.155	.085	.118	.128	.063
1939	.035	.039	.035	.042	ns	.070	.079	.070	.062	.014
1940	.030	.033	.034	.046	.010	.080	.083	.085	.085	ns
1941	.024	.030	.042	.044	.016	.092	.080	.092	.088	ns
1942	.038	.037	.048	.063	.015	.082	.080	.098	.128	.022
1943	.055	.052	.057	.067	.003	.090	.065	.070	.068	.017
Avg. for 9 crops	.026	.027	.030	.036	—	.070	.059	.066	.070	—

Crusher Juices: In Table III several crusher juice analyses are summarized for the nine crops harvested from each of the four treatments. From these data we get the following information:

(*a*) Cane quality, as indicated by yield per cent cane, has shown no consistently significant effect from the different sources of nitrogen. Averages for the separate harvests may indicate that cane quality in Treatment B (ammonium sulphate) has generally not come up to the level of the quality from Treatment C (nitrate of soda) or Treatment D (urea) but the differences are not statistically significant. The yield per cent cane from Treatment A (single application of ammonium sulphate) has been somewhat better than from Treatment B (split applications).

The purity figures (not tabulated) were not significantly different for treatments except in 1943 when Treatment A had a definitely higher purity than any of the other three treatments.

(*b*) In the first five crops with POJ 36 cane, the percentages of nitrogen in the crusher juices from ammonium sulphate (B) were generally higher than from the other two sources of nitrogen, but this condition has not been found since the variety was changed for the 1941 crop. We note also that the concentration of nitrogen in the juice at harvest has been less when ammonium sulphate was supplied in a single than when given in split applications.

(*c*) The gradual build-up of phosphoric acid in the juices from all treatments in more recent crops reflects undoubtedly the increased amounts of this nutrient which was supplied in the fertilizers (see Table I). This P_2O_5 concentration was generally higher in the cane fertilized with urea. Differences between nitrate of soda and ammonium sulphate were not proved, nor did the single application of ammonium sulphate affect the percentage of phosphate in the crusher juice any differently than did split doses.

(*d*) The percentages of potash in the crusher juices were so low in the 1935 and 1937 crops that potash fertilization for all four treatments was increased for the 1938 crop, and then stepped up again for the 1940 and subsequent crops. Urea produced cane with a higher percentage of potash in juice than either nitrate of soda or ammonium sulphate in 1935 and 1942, but in 1939 the potash concentration of cane fertilized with ammonium sulphate was greater than that from the urea-fertilized cane. No significant differences were noted between ammonium sulphate and nitrate of soda in their effect on this potash concentration. On two occasions the effect of a single application of ammonium sulphate was to increase the per cent K_2O in juice of its cane over that from the split applications.

TABLE IV

AVAILABLE (RCM) PHOSPHATE AND POTASH IN SOIL AT HARVEST

Crop year	Per cent P_2O_5 treatment A	B	C	D	Min. diff. req.	Per cent K_2O treatment A	B	C	D	Min. diff. req.
1939	.045	.045	.048	.046	ns	.0038	.0027	.0029	.0029	ns
1940	.020	.020	.016	.013	ns	.0035	.0029	.0030	.0060	.0016
1941	.022	.014	.010	.013	.006	.0030	.0025	.0028	.0028	.0003
1942	.023	.022	.014	.012	.006	.0026	.0026	.0029	.0026	ns
1943	.024	.021	.018	.016	.003	.0029	.0027	.0026	.0024	.0002

Soil Analyses: No significant differences between treatments were measured in the amounts of water-soluble nitrogen found in the soil at harvest. These amounts were seldom as much as ten parts per million and indicate a fairly complete uptake of the heavy nitrogen applications that were made to each crop.

Since 1939 the soil samples, taken with an auger to the full two-foot depth in each pot, have been analyzed by R.C.M. for their available phosphate and potash content. The data in Table IV do not indicate any great accumulation or building up of these available nutrients in this soil. The effects from the different nitrogen treatments indicate more available phosphate to be present in the soil fertilized with ammonium sulphate, but there is little difference between the other two nitrogen carriers in this effect on soil phosphate. The effects on available soil potash are not highly significant except in one instance (1940) when the urea apparently left more potash in the soil at harvest.

TABLE V

pH OF SOIL AT HARVEST

Crop year	Soil pH treatment A	B	C	D
1934	6.6	6.6	7.0	6.9
1935	6.3	5.9	7.2	6.7
1937	6.1	5.9	6.8	6.7
1938	5.4	5.1	6.4	6.2
1939	5.8	5.5	6.6	6.3
1940	5.0	5.0	6.7	6.0
1941	5.6	5.7	6.8	6.6
1942	5.1	4.9	7.0	6.8
1943*	4.9	4.6	6.2	6.0

* After harvest of the 1943 crop, soil samples analyzed by A. S. Ayres were found to have the following amounts of exchangeable calcium (Ca):

Treatment	m.e./100 gms.	lbs. CaO/acre ft.
A	2.43	1700
B	1.85	1300
C	8.78	6150
D	6.55	4600

Also, the ultimate pH of a composite sample from all four treatments was found to be 4.5.

Perhaps the most significant effect that has been identified in this study is that which the different nitrogen fertilizers have made upon the pH of this originally acid soil during its first ten years of intensive cropping (see Fig. 2 or Table V). We might compare the cumulative effect from the nine 42-gram applications of nitrogen supplied to the 420 pounds of soil in each container, with the use of 9000 pounds of nitrogen from one of three different nitrogen carriers, or sufficient for 45 crops of sugar cane if used at the rate of 200 pounds per acre in the field.

The soil samples were taken immediately after harvest with a one-half-inch auger to the full depth of the two-foot pot, and four borings per pot were composited and prepared for pH and other analyses. Although the original soil at time of potting had a pH of 5.3, its acidity was considerably reduced during the first three years of cropping, regardless of the source of nitrogen used. However, there is little doubt but that the ammonium sulphate has now produced a soil with a lower pH value than either nitrate of soda or urea; also, there is a consistent indication that the soil pH from the urea fertilization has been slightly lower than that from the nitrate of soda. Finally, there is no indication that the soil which has been heavily fertilized with nitrate of soda is becoming increasingly alkaline. In making these comparisons, we are not unaware of the fact that the irrigation water had a slightly alkaline reaction nor that the drainage waters have occasionally "flushed" these soils. Yet in spite of these wide differences in the present pH values of these soils, we have already seen (Table II) that neither the cane nor the sugar yields from this last 1943 crop has been differently affected. Thus it is apparent that sugar cane, grown under irrigation, can be made to produce very satisfactory crops of cane of good quality, even if the soil is or becomes very acid, providing of course that it is adequately furnished with plant nutrients which may be deficient in such soils.

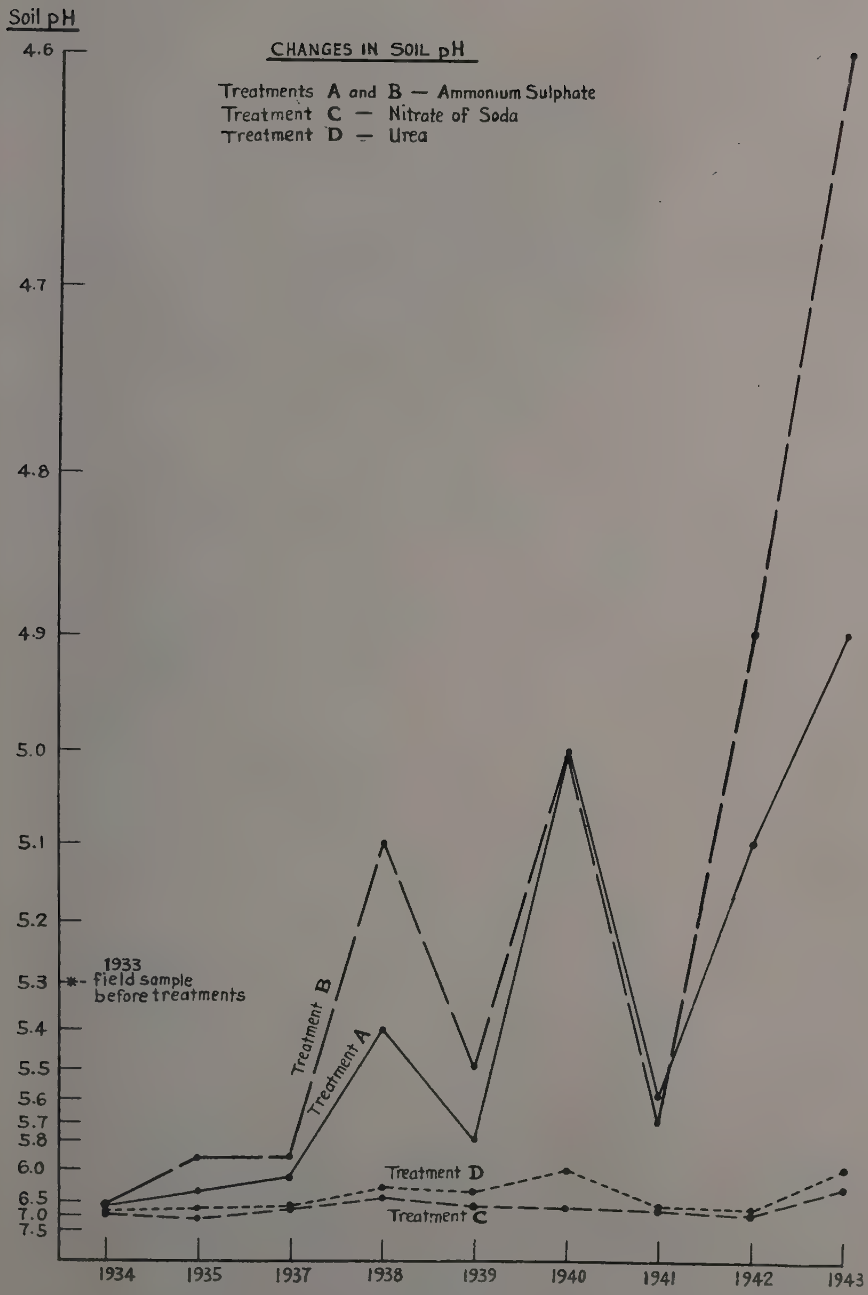

Soil pH
CHANGES IN SOIL pH
Treatments A and B — Ammonium Sulphate
Treatment C — Nitrate of Soda
Treatment D — Urea
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
6.0
6.5
7.0
7.5
1933 field sample before treatments
Treatment B
Treatment A
Treatment D
Treatment C
1934
1935
1937
1938
1939
1940
1941
1942
1943

Fig. 2.

Weed-spray Studies*

By R. J. Borden

The accompanying series of photographs, when studied with their respective legends, tells a story that needs only a little further elucidation to bring out their chief points of interest.

Most plantation men will agree that the weed *Eleusine indica,* commonly known as "wire-grass" and also as "goose grass," is one of the most persistent and difficult weeds to control in irrigated cane lands. Thus whatever we can learn regarding its destruction and its tolerance to the ordinary field-control, weed-spray practices, is worth-while information.

Figs. 1, 2, 3: This group of photographs should be studied together as their only point of difference is that which has resulted from the different dilutions of "Conc. 40" which were sprayed on this wire-grass when it was eight weeks old. In each figure the upper rows show the plants, which had developed under four different environmental conditions, at the time they were first sprayed. The spraying was thorough and all foliage above ground was completely wetted, and the results of the spraying are seen in the center rows. The lower rows show the effects at one month after the initial spraying; in the case of the two weaker dilutions, the original applications had been repeated after one week because they had not caused a satisfactory kill.

Fig. 1 shows that as early as one week after spraying, this tough weed was severely checked by the 1-to-20 dilution, and at one month all of the plants were completely dead. Fig. 2 shows that some kill, chiefly of the leaf blades, had occurred after one week where the 1-to-80 dilution was used, but these plants still had lots of green color left in them. Even the second spraying did not kill these plants which were growing in full sunlight, but a very complete kill of those growing in the shade of cane rows had occurred within the next few weeks. The effect from the initial 1-to-160 dilution after the first week, shown in Fig. 3, was little more than a "burning" of some of the leaves, and a definite "greening up" was taking place when this treatment was repeated. This second spraying with "Conc. 40" at 1-to-160 dilution was again ineffective on weeds which were grown in direct sunlight, but for those grown in the shade, even this very weak dilution soon effected a complete kill.

Figs. 4, 5, 6: This group of photographs shows the effects from the three dilutions of "Conc. 40" on wire-grass plants which were eight, six, four, and two weeks old when sprayed. All of these plants were similarly grown in full sunlight with ample soil moisture. Except where the 1-to-20 dilutions were used, the applications with the two weaker dilutions were repeated after one week as their initial kill was not complete.

Fig. 4 shows that all plants were ultimately killed by the initial application of "Conc. 40" diluted 1 to 20. In Fig. 5 we note a kill from the 1-to-80 dilutions that

* Project A 105—No. 83.2, in cooperation with the Chemistry Department who prepared and applied the herbicides used in this study.

was proportionately greater on the younger weeds. But of special interest is the evidence of individual plant tolerance to this dilution, for although each plant had been completely wetted by the spray, their reaction was different, *e.g.,* in flat No. 17, five four-week-old plants were killed but seven plants were only slightly checked, and in flat No. 20, two of the twelve two-week-old plants were able to survive their two sprayings with this 1-to-80 dilution. Finally Fig. 6 shows that when used at a 1-to-160 dilution, "Conc. 40" failed to kill any of the eight- and six-week-old plants, and killed only 25 per cent of those which were younger.

Fig. 7: This photograph shows the differential effects from several dilutions of "Conc. 40" and from two other herbicides upon the germination and growth of a few common weed seeds. *Flat No. 2*—When "Conc. 40" diluted 1 to 20 was sprayed on seeds of Spanish needle, amaranth, or purslane, which lay on the surface of the soil, their subsequent germination was nil. And although a few of the wire-grass seeds germinated, and a fair germination of foxtail occurred, their subsequent growth was very weak and sickly. *Flats Nos. 3 and 4*—The weaker dilutions of "Conc. 40" had proportionately less detrimental effects on seed germination and early growth. *Flat No. 5*—The soil-sterilizing effect of the activated sodium chlorate spray prevented a satisfactory growth from the few wire-grass and foxtail seeds which germinated, and stopped the germination of the other weed seeds. *Flat No. 6*—Neither the wire-grass nor the Spanish needle seeds were injured by the Diesel oil spray, although the germination of amaranth and purslane was completely stopped, and only a few foxtail plants appeared above ground.

Fig. 1. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with ''Conc.40'' *at 1-to-20 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.
No. 1—Grown in full sunlight with ample soil moisture.
No. 2—Grown in full sunlight with inadequate soil moisture.
No. 3—Grown in shade of cane rows with ample soil moisture.
No. 4—Grown in shade of cane rows with inadequate soil moisture.

Fig. 2. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with "Conc.40" *at 1-to-80 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

No. 5—Grown in full sunlight with ample soil moisture.
No. 6—Grown in full sunlight with inadequate soil moisture.
No. 7—Grown in shade of cane rows with ample soil moisture.
No. 8—Grown in shade of cane rows with inadequate soil moisture.

Fig. 3. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with "Conc.40" *at 1-to-160 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.
No. 9—Grown in full sunlight with ample soil moisture.
No. 10—Grown in full sunlight with inadequate soil moisture.
No. 11—Grown in shade of cane rows with ample soil moisture.
No. 12—Grown in shade of cane rows with inadequate soil moisture.

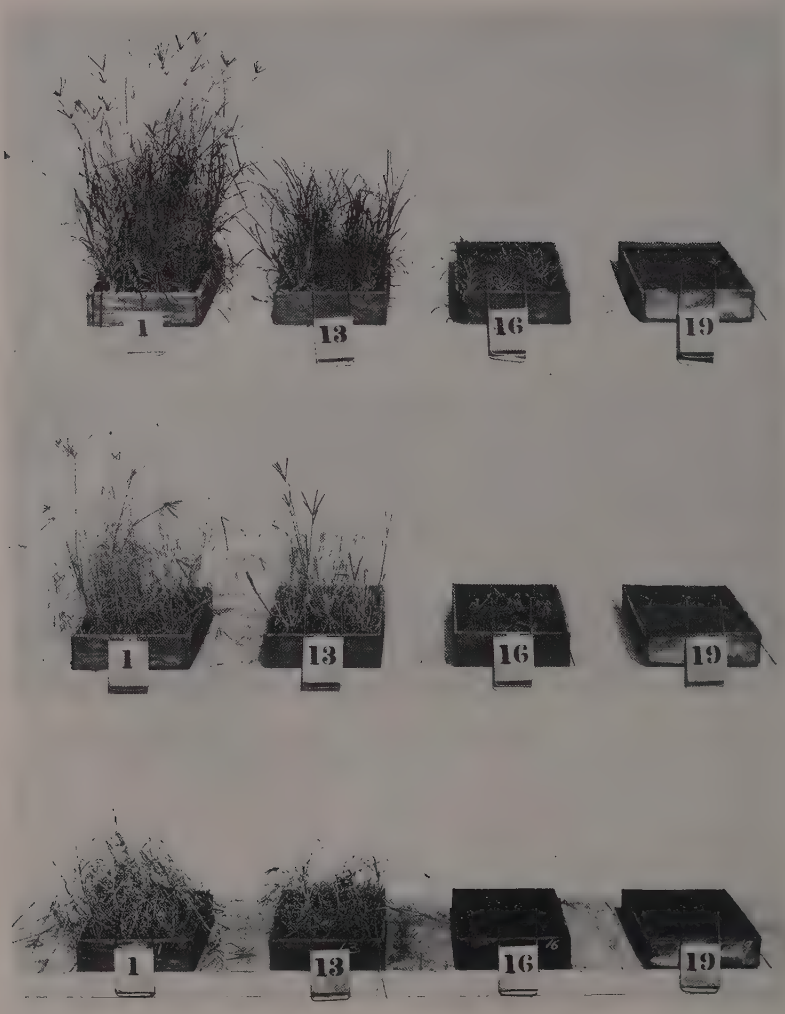


Fig. 4. Wire grass sprayed with "Conc.40" *at 1-to-20 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 1, 13, 16, and 19 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

Fig. 5. Wire grass sprayed with "Conc.40" *at 1-to-80 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 5, 14, 17, and 20 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

Fig. 6. Wire grass sprayed with "Conc.40" *at 1-to-160 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 9, 15, 18, and 21 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

Fig. 7. Effects of Various Herbicides on Weed Seeds.

In each flat, seeds of wire grass, foxtail, Spanish needle, amaranth, and purslane were dropped in rows (left to right) ¼″ deep. Both seeds and soil surface were then sprayed with the following herbicides:

1—Tap water (Control).
2—"Conc.40" diluted 1 to 20.
3—"Conc.40" diluted 1 to 80.
4—"Conc.40" diluted 1 to 160.
5—Activated sodium chlorate.
6—Diesel oil emulsion.

After spraying, the seeds were covered with soil, irrigated, and grown for 1 month before photographing.

The Synthesis of Sucrose in the Sugar Cane Plant—IV

Concerning the Mechanism of Sucrose Synthesis in the Sugar Cane Plant

By Constance E. Hartt

1. Phosphorylation, a part of the mechanism of interconversion and synthesis:

Phosphorylation, which means the formation of an organic compound with phosphate, is essential for the formation of starch from glucose, according to the work of Hanes (29), for the formation of glycogen from glucose, as proved by Cori (10, 11), as well as for other steps in intermediate carbohydrate metabolism. The steps in phosphorylation as determined in higher plants (peas, potatoes) by Hanes and in yeast and animals by Cori and others, may be outlined briefly in the following scheme, in which the enzymes which catalyze the reactions are placed in parentheses:

	Starch or glycogen + inorganic phosphate
	↓ ↑ (phosphorylase)
	Glucose–1–phosphate
	↓ ↑ (phosphoglucomutase)
Glucose ——————→	Glucose–6–phosphate→Phosphogluconic acid and further steps in
+ adenosine (hexokinase)	↓ ↑ (phosphohexoisomerase) [aerobic respiration
triphosphate	Fructose–6–phosphate
	↓ ↑ (phosphorylase)
	Fructose–1:6–diphosphate
	↓ ↑ (zymohexase)
	2 Triose phosphate
	↓ (Triose phosphate dehydrogenase)
	Further steps in fermentation

The absence of sucrose from this scheme is a glaring omission. Russian workers (47, 49) have presented evidence that phosphorylation is essential for the synthesis of sucrose. A similar conclusion was reached by Hassid (20A and 36).

In the sugar cane plant the following evidence, which was presented in detail in Parts I–III of this paper, indicates that phosphorylation is a part of the mechanism of the interconversion of glucose and fructose and of the formation of sucrose:

a. In the blades and roots of plants grown without phosphate, interconversion and synthesis did not take place as well as in plants grown with phosphate.

b. The addition of phosphate along with glucose aided the formation of sucrose by detached blades. This aid, however, appears to be an example of the proverb, "To him that hath shall be given," for in Part II of this paper it was shown that the addition of inorganic phosphate increased synthesis in blades of plants grown with phosphate but not in blades of plants grown without phosphate. This may be explained in two ways: (1) Perhaps the addition of inorganic phosphate to the blades of plants grown with phosphate checked the conversion of organic phosphate to inorganic phosphate and thus favored synthesis. (2) Perhaps the plants grown without phosphate had lost the mechanism for utilizing phosphate in synthesis.

c. The addition of bone phosphatase along with glucose decreased interconversion and synthesis. Since phosphatase releases inorganic phosphate from organic phosphate, this would indicate that phosphate must be in organic combination for interconversion and synthesis to take place. Bone phosphatase is known from the work of Liebknecht (52) to split off phosphate from adenosine triphosphate, which is the compound which donates phosphate to glucose, according to the scheme already presented. Bone phosphatase also hydrolyzes fructose diphosphate, according to Macleod and Robison (56).

d. Inhibiting the action of hexokinase, the enzyme which catalyzes the transfer of phosphate from adenosine triphosphate to glucose, resulted in the inhibition of interconversion and synthesis. It is extremely interesting that the information in the literature regarding the inhibition of hexokinase is entirely in agreement with the findings reported in Part III of this paper regarding the inhibition of interconversion and synthesis. Hexokinase is unaffected by cyanide or phloridzin and is inhibited by M/50 sodium fluoride, according to Case (8). Iri (40), however, reported that 0.01 M fluoride had no effect upon hexokinase. We found that fluoride (380 p.p.m. = 0.02 M = M/50) decreased synthesis considerably, whereas 0.01 M (= 190 p.p.m.) had much less effect. Iri also reported almost complete inhibition of hexokinase by 0.005 M iodoacetic acid, but incomplete inhibition with 0.002 M. These concentrations are between those used in this investigation, but show the same trend. Therefore the results of the effects of inhibitors upon interconversion and synthesis suggest that hexokinase, and hence phosphorylation, plays a part in both processes.

e. The ability of blades to carry on interconversion and synthesis fluctuated with the time of day at which the blades were detached from the plant, and the rhythm of fluctuation was the same as that of the movement of phosphate reported by Biddulph (4).

For the above reasons we believe that in the sugar cane plant glucose must react with phosphate before sucrose is formed. Referring again to the scheme of carbohydrate metabolism already presented, we note that the phosphorylation of glucose results in the formation of glucose–6–phosphate, *i.e.*, the phosphate is attached to carbon atom number 6. Glucose–6–phosphate is highly reactive and may follow one of at least three paths. It may form glucose–1–phosphate, phosphogluconic acid, or fructose–6–phosphate. Or it may lose its phosphate, which is not shown in the scheme. Which of these paths does the glucose–6–phosphate take on its way to forming sucrose?

The possibility that the path of sucrose formation is via glucose–1–phosphate, which is known to lead to the formation of starch and glycogen, cannot be overlooked because of the recent work of Doudoroff, Kaplan and Hassid (20a). Using a bacterial preparation, these workers obtained sucrose from glucose–1–phosphate and fructose. The formation of sucrose by the bacterial preparation was not affected by iodoacetic acid or fluoride and did not take place with glucose or fructose alone or together. But in the sugar cane plant sucrose is readily formed from either glucose or fructose, and this formation is inhibited by either iodoacetic acid or fluoride. Furthermore, the bacteria used by Doudoroff and co-workers were dried and ground, but in the sugar cane plant grinding absolutely prevents the formation of sucrose, as shown in Part I of this report. No tests have yet been conducted with

sugar cane, in which the formation of glucose–1–phosphate from glucose–6–phosphate is inhibited, or in which glucose–1–phosphate is supplied to detached blades, for which reason we cannot say that the sugar cane plant does or does not make sucrose from glucose–1–phosphate. But if this were the only pathway for the formation of sucrose in the sugar cane plant, how could inhibiting the formation of fructose diphosphate inhibit the formation of sucrose, and how could inhibiting the breakdown of fructose diphosphate increase the formation of sucrose?

The possibility that the path of sucrose formation might be via phosphogluconic acid was examined experimentally. Engelhardt (25) studied the changes of phosphogluconate in yeast maceration juice, and reported that non-phosphorylated gluconic acid behaves in untreated juice similarly to phosphogluconate. A test was therefore conducted using gluconic acid with and without phosphate, supplied to detached blades of the sugar cane plant, and absolutely no sugar was formed.

There remains the possibility that the path of sucrose formation from glucose is via fructose–6–phosphate. This possibility is attractive because the configuration of the sucrose molecule resembles that of both glucose and fructose, because sucrose upon hydrolysis yields both glucose and fructose, and because sucrose is formed in detached blades equally well from either glucose or fructose. Furthermore, the processes of interconversion of glucose and fructose and the formation of sucrose are intimately related, as they are similarly affected by many factors. Many factors have been studied which inhibit the interconversion of glucose and fructose, *e.g.*, lack of aeration, low temperature, arsenite, selenite, fluoride and others. Without exception, whenever the interconversion of glucose and fructose is inhibited, the formation of sucrose is also inhibited. In the experiment with etiolated plants, interconversion took place readily but synthesis was less than usual. In the experiments with brilliant alizarine blue and rosinduline GG, synthesis was affected much more severely than interconversion. Therefore it is possible to inhibit synthesis without inhibiting interconversion. But in these studies no factor has yet been found to inhibit interconversion without inhibiting synthesis. For this reason it seems clear that interconversion takes place either before synthesis or at the same time, and that the two processes are closely related.

Referring again to the scheme of carbohydrate metabolism, one may next inquire how far down the path via fructose–6–phosphate one must proceed before reaching the stepping stone necessary for the formation of sucrose.

To answer this question, let us first turn to the studies with iodoacetate. Weak iodoacetate, in a concentration known to inhibit triose phosphate dehydrogenase, had no effect upon interconversion or synthesis, for which reason "further steps in fermentation" need not be considered as the pathway towards sucrose formation. Iodine, silver nitrate, and copper sulphate, in concentrations known to inhibit zymohexase, increased the synthesis of sucrose a little. But brilliant alizarine blue and rosinduline GG, which inhibit the formation of fructose diphosphate from fructose–6–phosphate, inhibited the synthesis of sucrose.

Because inhibiting the formation of fructose diphosphate resulted in the inhibition of synthesis, whereas inhibiting the breakdown of fructose diphosphate resulted in increasing synthesis, fructose diphosphate is suggested as a necessary stepping stone in the formation of sucrose from glucose or fructose.

2. Aeration, a part of the mechanism of interconversion and synthesis:

Experiments reported in Part I of this paper demonstrated that aeration increases the absorption of glucose by detached blades or roots and is absolutely essential for the conversion of glucose to fructose and for the synthesis of sucrose. The exact rôle of aeration in interconversion and synthesis is not known, but may include (*a*) respiration, (*b*) phosphorylation, (*c*) aerobic synthesis, or (*d*) colloidal structure. These four factors will now be discussed.

(*a*) *Respiration:* Synthesis requires the expenditure of energy. Is this energy obtained by aerobic respiration? Although the exact chemical changes which take place in aerobic respiration in plants have not yet been definitely agreed upon, there is considerable evidence that at least two types of respiratory systems function, the cyanide-sensitive and the cyanide-stable. Results presented in Part III of this paper demonstrated clearly that neither interconversion nor synthesis was inhibited by cyanide. Furthermore, this finding was corroborated by tests with pyrophosphate, azide, and 8-hydroxyquinoline, which are among the most important inhibitors of iron-catalyzed and copper-catalyzed reactions. Apparently the oxidases, peroxidases, catalase, and other enzymes containing iron or copper are not involved in interconversion or synthesis, either directly or indirectly. D'yachkov (22), however, infiltrated leaves of cabbage, cyclamen and beets with peroxidase and found that it aided synthesis. This conclusion with sugar cane removes from our attention the greater part of aerobic respiration, since the cyanide-sensitive portion of respiration is greater than the cyanide-stable portion of respiration, and focuses our attention upon the cyanide-stable respiration, which is mediated by flavoprotein. A possible rôle of flavoprotein in synthesis is indeed suggested by the results presented in Part II of this paper, as riboflavin significantly increased synthesis in detached roots. However, this is not the whole story, as riboflavin had no effect upon interconversion, whereas aeration is as essential for interconversion as it is for synthesis.

(*b*) *Phosphorylation:* Not only is phosphorylation a part of the mechanism of interconversion and synthesis, as already discussed under that heading, but it is also a source of chemical energy used in cellular syntheses, according to Lipmann (53). Lipmann stated that there are several organic compounds of phosphate which contain energy-rich phosphate bonds. One of these compounds is adenosine triphosphate. As adenosine triphosphate donates phosphate to glucose, forming glucose–6–phosphate, considerable energy is released because the potential energy of adenosine triphosphate is about 10,000 calories while that of glucose–6–phosphate is about 3,000 calories. The energy thus released is used in organic syntheses, according to Lipmann. Since in this process, adenosine triphosphate loses its energy-rich phosphate bond, in order for the process to continue there must be a way in which more energy-rich phosphate bonds can be formed. Lipmann reviewed three ways whereby energy-rich phosphate bonds are formed: anaerobically by fermentation, and aerobically by alpha keto acid oxidation and dicarboxylic acid oxidation. The aerobic methods are more efficient than the anaerobic, as they yield more energy-rich phosphate bonds per molecule of glucose.

Since aeration is essential for interconversion and synthesis, whereas fermentation can be inhibited without interfering with interconversion and synthesis, the generation of energy-rich phosphate bonds in sugar cane is probably an aerobic process.

The method of alpha keto acid oxidation includes the dehydrogenation of pyruvate, which has been demonstrated in *Bacterium Delbrueckii,* brain, and kidney, and the oxidation of ketoglutarate, which has been demonstrated in kidney. In sugar cane, pyruvate has been used in several tests, and there was no evidence that it aided synthesis. Ketoglutarate has not yet been used.

The method of dicarboxylic acid oxidation includes the dehydrogenation of succinic, fumaric, and malic acids, which have been demonstrated in kidney. Szent-Györgyi's (79) theory of the rôle of the C_4 dicarboxylic acids in the respiration of animals is well known. In plants, Szent-Györgyi has stressed the importance of dihydroxymaleic acid, which is an oxide of succinic acid. Pucher and Vickery (71) have established the fact that succinic acid is widespread in plants, although it is only a minor constituent of leaves. Damodarau (15) reported the occurrence of succinic dehydrogenase in leguminous seedlings, and demonstrated the existence of the complete succinoxidase system in plants.

Although it appears well established that succinic acid and its dehydrogenase occur in plants and may take part in plant respiration, there is evidence against the theory that the dehydrogenation of succinate is essential for the phosphorylation of glucose in the sugar cane plant. Pyrophosphate, malonate, and sodium diethyldithiocarbamate are strong and specific inhibitors of succinic dehydrogenase, but did not inhibit synthesis.

Fumaric acid is converted to malic acid by the enzyme fumarase, for which no specific inhibitor is known to the writer. Fumaric acid increased synthesis a little, as reported in Part III of this paper.

Malic acid is a well-known constituent of plants. Vickery (82) has shown that malic acid increases in rhubarb leaves cultured in glucose in the dark and suggested that the metabolism of malic acid is connected with the metabolism of carbohydrate. In the leaves of Sudan grass, Wood (84) reported a correlation between respiration rate, sucrose, and malic acid. A comparison of the effects of inhibitors upon malic dehydrogenase as recorded in the literature with the effects of inhibitors upon the synthesis of sucrose reported in Part III of this paper is presented in Table I. The

TABLE I

THE EFFECTS OF INHIBITORS UPON MALIC DEHYDROGENASE COMPARED WITH THEIR EFFECTS UPON SUCROSE SYNTHESIS IN SUGAR CANE

Inhibitor	Effect upon malic dehydrogenase	Reference	Effect upon sucrose synthesis
Cyanide	Accelerated a little	Leloir & Dixon (50)	No effect (sometimes accelerated)
Arsenite	Inhibited (.15M)	Das (16)	
	Accelerated (.03M)	Green (27)	Inhibited
Iodoacetate (.01M)	Inhibited	Elvehjem (23)	Inhibited
Fluoride	No effect	Das (16)	Inhibited
Pyrophosphate	Accelerated	Green (27)	Accelerated
Malonate	No effect	Leloir & Dixon (50)	Little effect
Urethane	Inhibited a little	Green (27)	No effect

agreement is not perfect. Arsenite in as low a concentration as 5 parts per million decreases synthesis a little; but this may be due to an effect upon some other enzyme, since arsenite is a bad poison. The fact that fluoride, which depressed synthesis, has no effect upon malic dehydrogenase, need not throw that enzyme out of con-

sideration, for fluoride is known to inhibit hexokinase, as already mentioned. Malic dehydrogenase fits the picture much better than succinic dehydrogenase, but it is also possible that some other dehydrogenase is involved. Hibbert (38) reported a new oxidation-reduction system widespread in plants, consisting of methyl guaiacyl diketone and alpha hydroxypropiovanillone. Although much is known concerning the distribution of organic acids in plants, a considerable portion of the organic acid fraction is still "unknown acids." The possibility remains that one or more of these unknown acids with their dehydrogenases may be of importance in that part of aerobic respiration leading to the production of energy-rich phosphate bonds.

The theory that malic acid with its dehydrogenase may aid the formation of sucrose was tested by supplying malic acid with and without glucose to detached blades. The results of the determinations of moisture and sugars are recorded in Table II, and the gains in sugars and synthetic efficiencies in Table III. Malic acid

TABLE II

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT MALIC ACID (5 GMS/L) ADJUSTED TO pH 5 WITH NaOH

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	70.67 ± 0.057	0.523	2.281	2.941 ± 0.008
Water	71.10 ± 0.019	0.496 ± 0.002	1.692 ± 0.000	2.277 ± 0.001
Malic acid	71.23 ± 0.014	0.711 ± 0.002	1.933 ± 0.007	2.747 ± 0.009
Glucose	69.16 ± 0.052	1.149 ± 0.014	3.413 ± 0.016	4.742 ± 0.002
Glucose + malic acid	70.12 ± 0.019	1.094 ± 0.008	3.827 ± 0.023	5.123 ± 0.032

TABLE III

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT MALIC ACID (5 GMS/L) ADJUSTED TO pH 5 WITH NaOH, CALCULATED FROM TABLE II

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Water	—0.664	—0.589	
Malic acid	—0.194	—0.348	
Glucose	1.801	1.132	62.85
Glucose + malic acid	2.182	1.546	70.85

alone decreased the loss in total sugars and sucrose and may have substituted for sugar as a source of energy. Malic acid alone made no sucrose, but when given with glucose increased the gains in total sugars and sucrose and increased the synthetic efficiency. These results are in accord with the theory that malic acid aids in the synthesis of sucrose.

Therefore aeration is essential for interconversion and synthesis because the aerobic dehydrogenation of malic acid (or some related acid) forms the energy-rich phosphate bonds, and the energy-rich phosphate bond of adenosine triphosphate is transferred to glucose by hexokinase, forming glucose–6–phosphate, which constitutes the first step in both interconversion and synthesis.

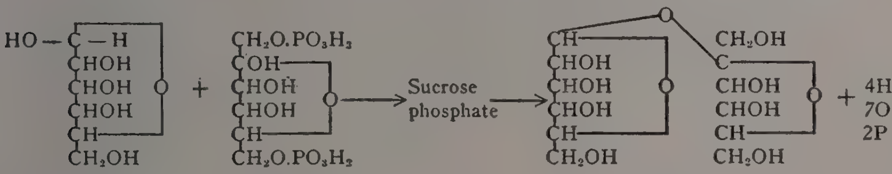
(*c*) *Aerobic synthesis:* Since the first step in both interconversion and synthesis requires aeration, it cannot yet be proved from our results that the final step in synthesis requires aeration. If we could supply blades with fructose diphosphate with and without aeration, we might determine whether aeration is required for the formation of sucrose from fructose diphosphate. Studies of this nature are now under way. Synthetic reactions in general require energy, and this energy comes from the phosphorylation of glucose, according to Lipmann.

(*d*) *Colloidal structure:* D'yachkov (22) is of the opinion that the energy of respiration is used for the maintenance of heterogeneity of living plasma required for synthesis. This theory was not tested in the present investigation.

Aeration, therefore, may aid interconversion and synthesis in more than one way: by facilitating the cyanide-stable respiration mediated by flavoprotein; and by facilitating the aerobic dehydrogenation of malic acid (also cyanide-stable) which is essential for the phosphorylation of glucose.

3. The conversion of fructose diphosphate to sucrose:

The final step to be discussed is the conversion of fructose diphosphate to sucrose. Consideration of the molecule of sucrose shows that half of the sucrose molecule closely resembles fructose diphosphate and the other half closely resembles glucose. If glucose should unite with fructose diphosphate, sucrose or its immediate forerunner might result, according to the following equation. The proposal



Glucopyranose

Fructofuranose diphosphate

Sucrose

of sucrose phosphate as the immediate forerunner of sucrose is justified by the fact that sucrose phosphates have been prepared (63), and enzymes capable of acting on sucrose phosphates are known to occur in both plants and animals (20, 62).

The above equation shows that the following would be left over: 4H, 7O, 2P. This might be accomplished in at least two ways: by the removal of one molecule of pyrophosphoric acid ($H_4P_2O_7$), or by the simultaneous removal of one molecule of water and two molecules of metaphosphoric acid ($H_2O + 2HPO_3$).

Now it is conceivable that the phosphate might go off in the inorganic form or that it might be taken by an organic phosphate acceptor. If the phosphate goes off in the inorganic form, there should be an increase in inorganic phosphate in cane during ripening. Ayres (2) reported that the percentage of phosphate in the stalk decreased from 4 to 8 months and then remained the same until 14 months, but he did not distinguish between organic and inorganic phosphate. If the phosphate goes off in the inorganic form, the process should be aided by a phosphatase and phosphatase should increase the formation of sucrose; but, as shown in Part II of this paper, bone phosphatase decreased synthesis. But a specific phosphatase, differing from bone phosphatase, may be required to split sucrose phosphate. Neuberg (62) reported that sucrose phosphoric acid is converted by kidney phosphatase into sucrose and phosphoric acid. Pratesi (70) discovered that phosphatase extracted from the leaves of geranium, rose, lily and violet splits calcium sucrose phosphate, the action being best at pH 4.2–6.7.

The possibility that the phosphate is taken by an organic phosphate acceptor will now be considered. Cocarboxylase is known to be the pyrophosphoric acid ester of vitamin B_1. The yellow enzyme is a riboflavin-phosphoric acid-protein complex. Both vitamin B_1 (= thiamin) and vitamin B_2 (= riboflavin) must obtain phos-

phate from someplace, and either of them might act as the organic phosphate acceptor needed for the formation of sucrose from glucose and fructose diphosphate. Harris (30) reported that vitamin B_1 is phosphorylated through the agency of adenosine triphosphate. Horowitz (39) found that in the pea, carboxylase is partially inactivated by its action on pyruvate, that vitamin B_1 is released by this inactivation, and that the enzyme can be reactivated by adding pyrophosphate.

Evidence that thiamin and riboflavin aid in the synthesis of sucrose was presented in Part II of this paper. Of considerable interest is the absence of any evidence that these vitamins aid in the interconversion of glucose and fructose, which would only be expected if their function is to remove the phosphate from sucrose phosphate. Etiolated shoots were found to lack something necessary for synthesis but were well able to carry on the interconversion of glucose and fructose, for when supplied with glucose they accumulated fructose, and when supplied with fructose they accumulated glucose, as reported in Part I of this paper. Etiolated shoots are known to contain auxins but to lack certain vitamins, including thiamin and riboflavin. Roots were found to obtain something essential for synthesis from tops; this "something" was found to be air and probably something else. Roots are known to obtain certain vitamins from tops, including thiamin and riboflavin.

For these reasons it is suggested that thiamin or riboflavin may aid in the synthesis of sucrose by removing phosphate from sucrose phosphate, with or without the aid of a specific phosphatase.

This section is headed "The conversion of fructose diphosphate to sucrose." The evidence that this conversion takes place is purely circumstantial, as such a reaction has not yet actually been observed in the test tube. Studies with fructose diphosphate designed to test the theory directly are now in progress.

4. Conclusion:

The mechanism of the synthesis of sucrose in the sugar cane plant includes phosphorylation and aeration. With the aid of hexokinase, some of the glucose absorbed by the blades is phosphorylated by the energy-rich phosphate bond of the adenosine triphosphate already present in the blades. This aerobic process results in the formation of more energy-rich phosphate bonds, perhaps by the dehydrogenation of malic acid, and these bonds are used for the reformation of adenosine triphosphate. Some of the phosphorylated glucose is converted to fructose monophosphate and then to fructose diphosphate. Some of the fructose diphosphate may be broken down anaerobically, but most of it combines with glucose using the energy released by phosphorylation, forming a sucrose phosphate. A phosphate acceptor such as thiamin or riboflavin, with perhaps the aid of a specific phosphatase, accepts the phosphate and thus sucrose is formed.

These reactions, though long in the telling (and in the reading) probably take place practically instantaneously in the plant.

Fructose is just as good a substrate as glucose for the synthesis of sucrose. Following the outline presented for glucose, the phosphorylation of fructose should result in the formation of fructose–6–phosphate. Some of this fructose monophosphate would need to be converted to fructose diphosphate, while some would be changed to glucose monophosphate and then to glucose. The glucose would then combine with the fructose diphosphate, resulting in the formation of sucrose phosphate. Thus the formation of sucrose would take place by the same mechanism

whether glucose or fructose is the starting point. The only difference is that both of the reactants have to be made when fructose is supplied, whereas only one reactant has to be made when glucose is supplied.

The formation of sucrose in the plant results not only in a storing of sugar which thus is not all broken down at once, but also in the release of phosphate which can be used again.

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The Early Development and Rate of Nutrient Uptake by Sugar Cane

By R. J. Borden

Studies of the early development of a sugar cane crop and of the nature of its nutrient uptake provide basic information for the sugar cane agriculturist whose interest is in providing an optimum nutriment for his crop.

This present study shows some of the relationships in cane which was started at different times during the year and harvested at comparative growth stages thereafter. All parts of the crop have been periodically collected, weighed, and analyzed for their concentration of the three principal plant foods, and from the data obtained a picture of the rate of development and of nutrient uptake forms the principal basis for the ensuing presentation.

An addition to the work of previous investigators who have studied the development and the uptake of nitrogen, phosphoric acid, and potash by the sugar cane plant can now be made from the results which have been summarized from our Project A 105—No. 132.* Although the data cover a period of only the first 12 months of growth of H 109 cane, this period is recognized as a critical one insofar as nutrient supply and absorption are concerned, and a better understanding of this early nutrient uptake should lead to a better knowledge of the rate at which sugar cane prefers to take up its mineralized plant food.

Since it was desirable to secure data to show the *total* uptake of N, P_2O_5, and K_2O, it was necessary to plan the investigation so that all vegetative growth including abscissed leaves and all roots could be recovered. This necessitated recourse to a controlled pot culture, and we made use of 16-inch diameter concrete pots, each filled with 52 pounds of a well-mixed soil, and located at Makiki for convenience in handling.

In order to avoid a bias on nutrient uptake, which can follow from the usual method of applying several doses of commercial fertilizer to growing cane, we made several trials before a satisfactory technique was found. Under natural soil conditions, nitrogen becomes available through a series of complex biological and chemical changes in the soil. Under the more artificial conditions of modern sugar cane growing, the natural supply of nitrogen is supplemented by several heavy applications of chemical nitrogen. When nitrification works on these natural supplies the plant gets its nitrogen gradually, but from the artificial supply it gets a large amount all at once, and if given this chance to gorge itself this fact may have a very different effect upon its natural rate of uptake, not only of its nitrogen but also of phosphate and potash.

As finally installed, we used a mixture of two-thirds Manoa soil and one-third compost, limestone, superphosphate, and muriate of potash with bentonite (50–50)

* Prepared, planted, fertilized, harvested, and samples prepared by L. R. Smith, A. Y. Ching, Y. Yamasaki, and various Assistants-in-Training. All chemical analyses by H. M. Lee.

Fig. 1.

First column	Second column	Third column	Fourth column
Series I	Series II	Series III	Series IV
Planted Nov. 16.	Planted Feb. 15.	Planted May 15.	Planted Aug. 15.

Top row, 6th leaf-stage. Second row, 12th leaf-stage. Third row, 18th leaf-stage. Bottom row, 24th leaf-stage.

Fig. 1 (continued).
Top row, 30th leaf-stage. Middle row, 36th leaf-stage. Bottom row, 45th–48th leaf-stage.

to provide the basic medium in which the cuttings of H 109 were planted. Subsequently the nitrogen was supplied entirely from dried blood mixed with fresh soil and scratched into the surface of the soil in each pot at intervals of 500 day-degrees until the assumed total nitrogen requirement for the 12-month crop had been furnished. By this procedure it was believed that nitrogen uptake, which could not take place until this organic material was broken down by soil microorganisms, would be more nearly the natural uptake by the sugar cane crop. Subsequent observations of its growth showed that the cane was getting an adequate supply of nitrogen from these dried blood applications. Hence this plan was followed for four consecutive plantings or series: No. I planted on November 16, No. II on February 15, No. III on May 15, and No. IV on August 15—all in a soil medium which had been thoroughly mixed and potted before Series I was installed.

Harvesting periods for three pots in each series were originally specified at the unfolding of the 6th, 12th, 18th, 24th, 30th, 36th, and 42nd leaf blade, but a short time prior to the 42nd "leaf-stage" in Series I it was decided to carry the last group of three pots through to an age of 12 months before harvesting them.

Photographs of an average pot in each series were taken to record the comparative stages of development at each harvest. These are shown in Fig. 1, and should be studied with the following facts in mind:

ACTUAL DATES AND AGES (WEEKS) AT WHICH THE CONSECUTIVE LEAF-STAGES WERE REACHED

	Series I		Series II		Series III		Series IV	
Leaf-stage	Date	Age	Date	Age	Date	Age	Date	Age
6th	Jan. 25	10	Apr. 18	9	Jul. 3	7	Oct. 7	7
12th	Mar. 5	16	May 24	14	Aug. 7	12	Nov. 18	13
18th	Apr. 17	22	Jul. 3	20	Sept. 11	17	Dec. 26	19
24th	Jun. 3	29	Aug. 7	25	Oct. 28	24	Feb. 13	26
30th	Jul. 23	36	Sept. 19	31	Dec. 16	30	Apr. 8	33
36th	Aug. 28	41	Oct. 28	37	Jan. 27	36	May 16	39
42nd	—	—	—	—	—	—	Jun. 30	45
45–48th	Nov. 18	52	Feb. 13	52	May 15	52	Aug. 15	52

The total weights were secured of all "above-ground" parts which included tops, stalks, and all dry trash collected during the growth period concerned, and of all "below-ground" parts which included all roots and stubble and seed pieces below the ground level. The entire amounts produced in each pot were carefully ground up for samples that were subsequently dried and analyzed. The complete data are given in Tables IV to VII, and may be discussed therefrom or from the accompanying figures whereon the numerical data are plotted.

Concentration of Nutrients:

The changes which took place in the concentration (%) of nutrients in the total dry weight as each successive leaf-stage was reached are shown in Table I.

TABLE I

AVERAGE CONCENTRATION (%) OF NUTRIENTS

(Average of 4 Series)

		Leaf-stage							
		6th	12th	18th	24th	30th	36th	42nd*	45–48th
Above-ground parts	N	1.81	1.55	.93	.70	.59	.49	.45	.34
	P_2O_5	.76	.63	.52	.46	.35	.30	.27	.25
	K_2O	3.08	2.69	2.16	1.52	.98	.61	.59	.34
Below-ground parts	N	.74	.81	.68	.65	.66	.65	.56	.59
	P_2O_5	.52	.41	.32	.29	.29	.28	.26	.26
	K_2O	1.39	1.24	.94	.55	.32	.27	.32	.23

* Only Series IV.

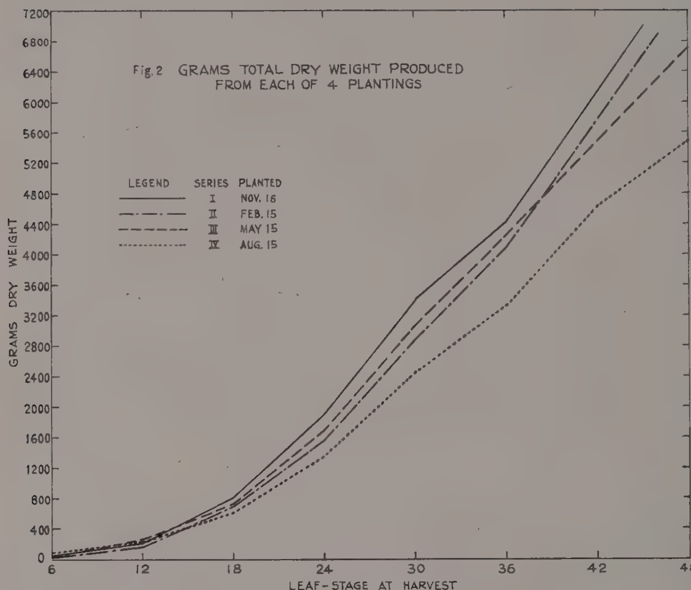
The percentage concentration of all nutrients decreased as the crop grew older. This decrease was considerably larger in the above-ground parts of the crop than in the roots and stubble that grew below ground. It is a factor that will need consideration in any attempt to determine critical concentration levels because a representative sample from a sugar cane crop will include stalks which have reached many different leaf-stages of development.

During the early stages, the concentration of nitrogen in the above-ground portions was higher than that in the parts below ground, but shortly after the 24th leaf was formed this relationship was reversed and thereafter the percentage of nitrogen found in the parts below ground was slightly the higher. This same reversal, however, was not found for the per cent potash or phosphate.

Dry Weight:

In studies of nutrient uptake, the percentage-composition figures can be the objects for incorrect interpretation unless the dry weight figures are also available, because the concentration of any one ingredient in the plant material is positively influenced by the extent to which the sample is diluted with other substances. Thus Fig. 2 is given to show the comparative amounts and rates in the production of total dry matter produced in each of the four series planted.

Except for Series IV planted in August, the dry weights at comparable stages of leaf development were perhaps not significantly different for the crops which were started in the different seasons, and the rates at which dry matter was produced were quite similar during their initial 12-month growth periods. The total production of dry matter was slow until the primary stalks had acquired their first 12 leaves; then, while they were forming another 6 leaves, the total dry weight doubled. This later figure, *i.e.,* at the 18th leaf-stage, was again doubled by the time 24 leaves had been produced, and this in turn had again almost doubled by the time the 30th leaf appeared. Thereafter, the rate at which the dry matter was formed continued, but without doubling, at about the same as between the 24th and 30th leaf-stages. Since during the first 9 months the average time between the unfolding of successive leaves was only 7 days, it is evident that this multiple period of increase in dry weight came between 84 and 210 days after planting, or approximately between the 3rd and 7th months; thus this is indicated as a most critical period in the development of the crop and one during which we infer that there should be no shortage of plant food or water if full returns are to be obtained.



SERIES	ACTUAL DATES HARVESTED							
I	1/25	3/5	4/17	6/3	7/23	8/28	—	11/18
II	4/18	5/24	7/3	8/7	9/19	10/28	—	2/13
III	7/3	8/7	9/11	10/28	12/16	1/27	—	5/15
IV	10/7	11/18	12/26	2/13	4/8	5/16	6/30	8/15

Fig. 2.

Uptake of Nitrogen:

All series were being supplied with nitrogen, from dried blood at 500 day-degree intervals until shortly after the 36th leaf blade had unfolded, at 30 grams per pot for the first three and at 60 grams for the next five applications. In Fig. 3 there is shown a considerable similarity between the four series of crops in the totals and rates of uptake of their nitrogen. Thus a cane crop which had not reached its 18th leaf-stage (generally between 4 and 5 months) took up nitrogen from an equivalent supply at very similar rates and amounts. Between its 18th and 30th leaf-stage, the rates of nitrogen absorption were much faster than before this growth stage, and except for Series II which encountered the effects of the winter months at this time, these rates were again quite similar during the other seasons of the year. The effect of this interaction between the 18th-30th leaf-stage of growth and the winter months, upon the total nitrogen uptake, is primarily due to the decreased amount of dry matter, for the percentage of nitrogen in the trash, tops, and cane was actually higher than in the other three series during this season.

After the 30th leaf-stage was reached, the nitrogen absorption rates for Series I, II, and III slowed up and were again quite similar to those of the early stages; and at the 36th leaf-stage the total amounts which had been taken up by each series were again not very different.

Uptake of Phosphate:

The total amounts and the rates at which phosphate was absorbed, although lower and slower than for nitrogen, show a certain degree of parallelism. (Com-

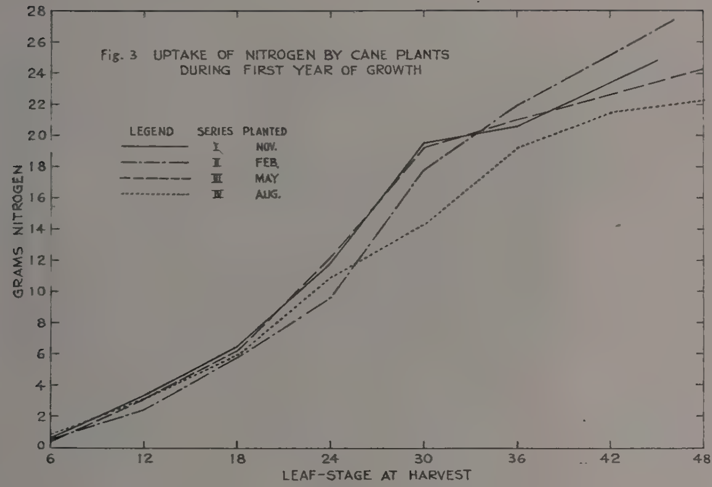


Fig. 3 UPTAKE OF NITROGEN BY CANE PLANTS
DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV.
II FEB.
III MAY
IV AUG.
GRAMS NITROGEN
LEAF-STAGE AT HARVEST
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
6 12 18 24 30 36 42 48

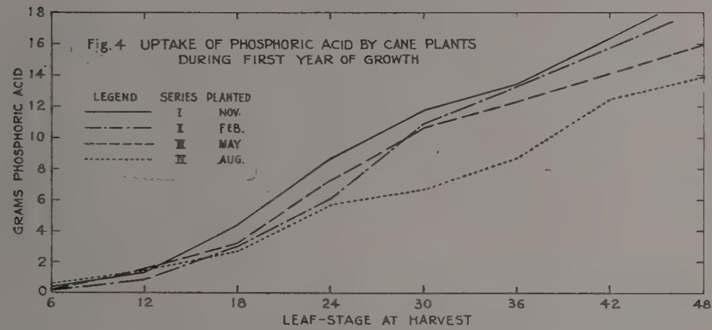


Fig. 4 UPTAKE OF PHOSPHORIC ACID BY CANE PLANTS
DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV.
II FEB.
III MAY
IV AUG.
GRAMS PHOSPHORIC ACID
LEAF-STAGE AT HARVEST
0 2 4 6 8 10 12 14 16 18
6 12 18 24 30 36 42 48

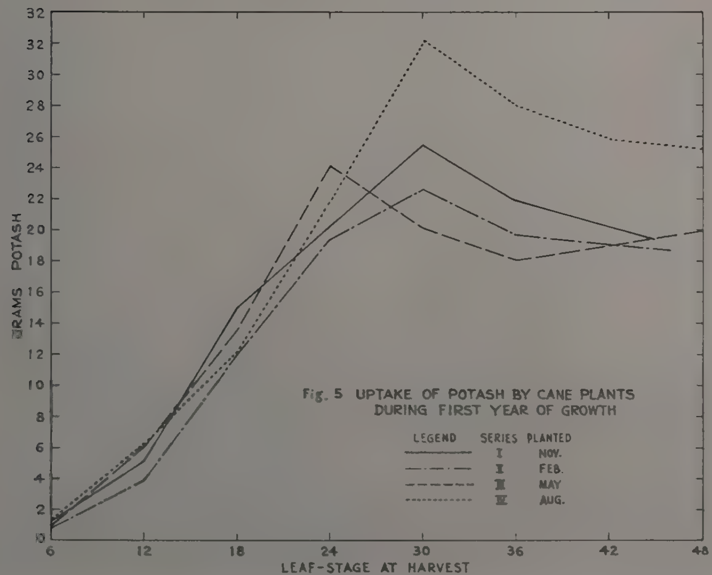


Fig. 5 UPTAKE OF POTASH BY CANE PLANTS
DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV.
II FEB.
III MAY
IV AUG.
GRAMS POTASH
LEAF-STAGE AT HARVEST
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 32
6 12 18 24 30 36 42 48

Figs. 3, 4, 5.

pare Fig. 4 with Fig. 3.) The rate of phosphate absorption during the early growth period, while only about half as fast as for nitrogen, was quite constant and without further increase after the crop had reached its 12th leaf-stage.

The total phosphate uptake by plants in Series IV fell below that of the other three series after the 12th leaf-stage had been passed. This was largely due to the lower yield of dry matter although at the 30th and 36th leaf-stages the percentage of P_2O_5 in the dry matter of the above-ground parts of this series was also lower.

Uptake of Potash (Fig. 5):

The early uptake of potash was at a faster rate than the corresponding uptake of nitrogen, not only between the unfolding of the 6th and 12th leaves but also immediately thereafter, until 24 or 30 leaves had been grown.

Unlike both nitrogen and phosphate, all four series show a sharp break in their potash curves in the second halves of their growth periods. This break occurred after the 24th leaf-stage in Series III but not until the 30th leaf-stage in the other three series. Since the 24th leaf-stage for Series III was reached in late October, it appears that the less-favorable or winter climatic conditions immediately thereafter may have been responsible for this somewhat earlier loss of potash.

The actual loss of potash from these crops during their later growth stages was a loss which took place from the above-ground parts only, for the below-ground portions did not show corresponding losses. Since all dry trash was saved and included in the samples analyzed, this loss of potash cannot be explained as an actual loss of some of the dry matter. Hence it appears that potash has actually moved out of the cane plant—perhaps back into the soil as some plant investigators have suggested.

Average Amounts and Rates of Absorption:

In Figs. 6 and 7 we have brought together all the data from Figs. 3, 4, and 5 to show: (*a*) the comparative amounts of nitrogen, phosphate, and potash that were found in the total dry matter which had been produced at successive leaf stages of development, and (*b*) the comparative rates at which these three nutrients were absorbed. They illustrate, quite simply, the general relationships already discussed.

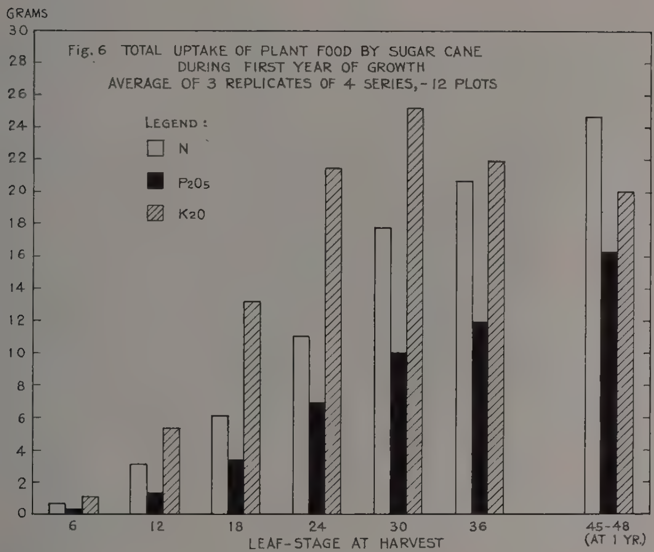
Proportions Found Below and Above Ground:

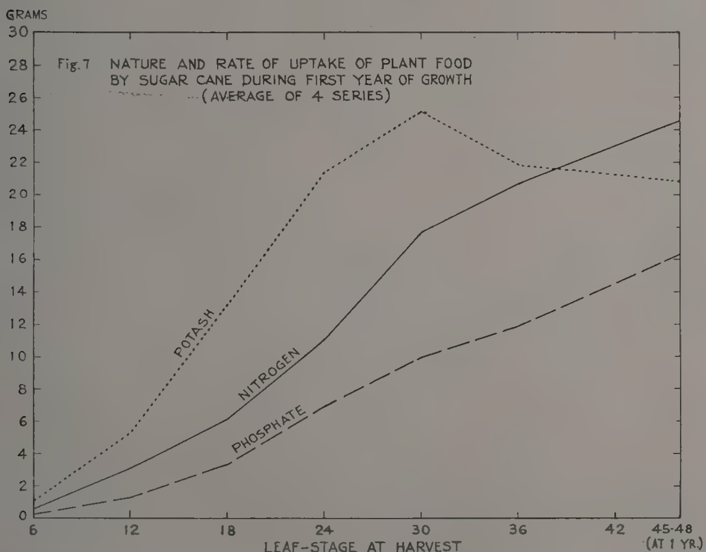
The figures in Table II show the approximate proportions of the total dry weight as found both below and above ground at successive harvests, and the corresponding proportions in the concentration of the three major nutrients studied.

TABLE II

PROPORTION OF BELOW-GROUND TO ABOVE-GROUND PARTS AT SUCCESSIVE HARVESTS

		In concentration of nutrients		
Leaf-stage	In total dry wt.	N	P_2O_5	K_2O
6th	1.91	.41	.69	.45
12th	.40	.52	.64	.46
18th	.32	.74	.61	.44
24th	.23	.93	.63	.36
30th	.20	1.15	.83	.32
36th	.19	1.32	.94	.44
45–48th	.18	1.72	1.04	.66





Figs. 6, 7.

These figures may be found useful in estimating the amounts of nutrients in the roots and stubble, which would usually be left in the field after harvesting, from actual measurements of nutrients which could be more easily determined from samples of the above-ground parts. For example: At the 36th leaf-stage, the amounts of roots, stubble, and seed pieces in our study was .19 of the amount of dry matter produced above ground. Thus if it were known that the above-ground crop averaged, let us say 15 tons per acre of total dry weight (which would be equivalent to

approximately 60 tons green weight, made up of about 46 tons of stalks and 14 tons of tops and trash), it could be assumed that .19 of 15 tons or 2.85 tons of dry weight would be left in the soil. Then, if an analysis of samples of the dry weight of the above-ground parts were to show .49 per cent N, it would be assumed that their corresponding below-ground parts would average about 1.32 times .49 per cent or .65 per cent N. Thus this 2.85 tons of dry matter at .65 per cent N would leave something in the order of 37 pounds of nitrogen behind in the soil at harvest, whereas the remainder, some 12.15 tons of stalks and leaves at .49 per cent N, would mean that about 119 pounds of nitrogen would leave the field as the crop was taken away.

In a similar manner the approximate amounts of P_2O_5 and K_2O which would be left behind in the soil would be estimated from an analysis of the above-ground parts harvested. Thus if these showed .30 per cent P_2O_5 and .61 per cent K_2O, we would estimate that these 2.85 tons of dry weight below ground averaged .94 times .30 per cent or .28 per cent P_2O_5, and .44 times .61 per cent or .27 per cent K_2O, and so would leave behind some 16 pounds of phosphate and 15 pounds of potash, while some 73 pounds of phosphate and 148 pounds of potash were being taken away.

A segregation of the "above-ground" parts at each harvest, to show the percentages of their total dry weights represented in (*a*) the millable cane, (*b*) the green tops, and (*c*) all trash or dry leaves which had accumulated, is given in Table III.

TABLE III
SEGREGATION OF TOTAL DRY WEIGHT AS FOUND IN THE ABOVE-GROUND PARTS

	Approximate per cent of total		
Leaf-stage	As cane	As tops	As trash
6th	—	100	—
12th	—	100	—
18th	28	72	—
24th	42	51	7
30th	52	34	14
36th	55	29	16
45–48th	58	15	27

The millable cane at the final harvest amounted to only 58 per cent of the total dry weight which had been produced above ground. The percentage represented by the tops decreased as the crop grew older and at the end of a year was not unlike the percentage of tops we have found in previous studies. At the time the 18th leaf appeared, there had been no dropping off of the old leaves, although some of them had undoubtedly ceased to function at this time, and perhaps their dry weight should have been deducted from "tops" and included as "trash"; in all subsequent harvests all dry leaves were so included. In connection with the trash accumulation, we find that this part of the crop amounts to fully one-quarter of the total dry matter produced above ground at the age of 12 months.

Summary

From periodic harvests of sugar cane which was started in different seasons, we have recorded the rates at which the crop has developed, and the N-P-K composition of both the below- and above-ground portions. From these data we find the following of sufficient interest to summarize:

1. The concentration of nitrogen, phosphate, and potash has decreased with an increase in age.

2. The rates at which dry matter was produced were quite similar except for the crop which was planted in August. Apparently the winter weather influenced this planting at the age when it should have been doubling its weight.

3. The most rapid uptake of nitrogen occurred between the appearance of the 18th and 30th leaves—roughly from 4 to 9 months. Winter weather during this growth period decreased the rate of nitrogen absorption.

4. Phosphate absorption was quite constant after the crop was well under way.

5. In the early stages, potash was taken up at a very rapid rate. About midway in the growth period, an actual loss of potash from the plant tissues took place.

6. A possible utilization of the data secured may be made in estimating amounts of the major nutrients in those parts of a cane crop which develop below ground.

TABLE IV

SUMMARY OF YIELDS AND ANALYSES OF SERIES I—PLANTED NOV. 16

(Averages of 3 Replicates at Each Harvest)

	Harvested: Leaf-stage / Date / Age (weeks)	6th Jan. 25 10	12th Mar. 5 16	18th Apr. 17 22	24th Jun. 3 29	30th Jul. 23 36	36th Aug. 28 41	45th Nov. 18 52
Above-ground parts (tops, cane and trash)	Grams dry wt.	24	157	606	1534	2817	3644	5800
	% N	1.70	1.80	.90	.62	.56	.43	.31
	% P_2O_5	.78	.70	.63	.48	.36	.30	.25
	% K_2O	3.01	2.68	2.15	1.24	.85	.55	.29
	Gms. N	.41	2.83	5.45	9.51	15.78	15.67	17.98
	Gms. P_2O_5 ...	.19	1.10	3.82	7.36	10.14	10.93	14.50
	Gms. K_2O ...	.72	4.21	13.03	19.02	23.94	20.04	16.82
Below-ground parts (roots, stubble, and seed piece)	Grams dry wt.	35	71	205	365	600	803	1215
	% N	.79	.81	.55	.65	.63	.62	.57
	% P_2O_5	.53	.42	.32	.35	.28	.32	.28
	% K_2O	1.37	1.32	.99	.35	.27	.23	.22
	Gms. N	.28	.58	1.13	2.37	3.78	4.98	6.93
	Gms. P_2O_5 ...	.19	.30	.66	1.28	1.68	2.57	3.40
	Gms. K_2O ...	.48	.94	2.03	1.28	1.62	1.85	2.67
Totals (entire crop)	Grams dry wt.	59	228	811	1899	3417	4447	7015
	Gms. N	.69	3.41	6.58	11.88	19.56	20.65	24.91
	Gms. P_2O_5 ...	.38	1.40	4.48	8.64	11.82	13.50	17.90
	Gms. K_2O ...	1.20	5.15	15.06	20.30	25.56	21.89	19.49

TABLE V

SUMMARY OF YIELDS AND ANALYSES OF SERIES II—PLANTED FEB. 15

(Averages of 3 Replicates at Each Harvest)

Harvested	Leaf-stage / Date / Age (weeks)	6th Apr. 18 9	12th May 24 14	18th Jul. 3 20	24th Aug. 7 25	30th Sept. 19 31	36th Oct. 28 37	46th Feb. 13 52
Above-ground parts (tops, cane and trash)	Grams dry wt.	14	116	481	1227	2344	3408	5894
	% N	1.84	1.68	.82	.61	.60	.50	.34
	% P_2O_5	.79	.65	.47	.42	.39	.33	.25
	% K_2O	3.17	2.85	2.09	1.41	.90	.53	.28
	Gms. N	.26	1.95	3.94	7.48	14.06	17.04	20.04
	Gms. P_2O_5 ...	.11	.75	2.26	5.15	9.14	11.25	14.74
	Gms. K_2O ...	.44	3.31	10.05	17.30	21.10	18.06	16.50
Below-ground parts (roots, stubble, and seed piece)	Grams dry wt.	34	59	220	336	533	678	1054
	% N	.84	.81	.87	.61	.71	.73	.68
	% P_2O_5	.48	.40	.35	.28	.34	.31	.27
	% K_2O	1.29	1.14	.92	.64	.29	.25	.21
	Gms. N	.29	.48	1.91	2.05	3.78	4.95	7.17
	Gms. P_2O_5 ...	.16	.24	.77	.94	1.81	2.10	2.85
	Gms. K_2O ...	.44	.67	2.02	2.15	1.55	1.70	2.21
Totals (entire crop)	Grams dry wt.	48	175	701	1563	2877	4086	6948
	Gms. N	.55	2.43	5.85	9.53	17.84	21.99	27.21
	Gms. P_2O_5 ...	.27	.99	3.03	6.09	10.95	13.35	17.59
	Gms. K_2O ...	.88	3.98	12.07	19.45	22.65	19.76	18.71

TABLE VI

SUMMARY OF YIELDS AND ANALYSES OF SERIES III—PLANTED MAY 15

(Averages of 3 Replicates at Each Harvest)

Harvested	Leaf-stage / Date / Age (weeks)	6th Jul. 3 7	12th Aug. 7 12	18th Sept. 11 17	24th Oct. 28 24	30th Dec. 16 30	36th Jan. 27 36	48th May 15 52
Above-ground parts (tops, cane and trash)	Grams dry wt.	13	208	565	1398	2596	3599	5787
	% N	1.88	1.32	.95	.74	.61	.47	.33
	% P_2O_5	.79	.61	.50	.47	.36	.30	.24
	% K_2O	3.08	2.44	2.18	1.64	.72	.46	.31
	Gms. N	.24	2.75	5.37	10.28	15.84	16.92	19.10
	Gms. P_2O_5 ...	.10	1.27	2.82	6.53	9.35	10.80	13.89
	Gms. K_2O ...	.40	5.08	12.32	22.78	18.69	16.56	17.94
Below-ground parts (roots, stubble, and seed piece)	Grams dry wt.	34	71	141	285	492	672	904
	% N	.62	.82	.62	.68	.69	.62	.56
	% P_2O_5	.55	.40	.32	.26	.26	.23	.23
	% K_2O	1.59	1.34	.96	.48	.31	.24	.22
	Gms. N	.21	.58	.87	1.94	3.39	4.17	5.06
	Gms. P_2O_5 ...	.19	.28	.45	.74	1.28	1.55	2.08
	Gms. K_2O ...	.54	.95	1.35	1.37	1.53	1.61	1.99
Totals (entire crop)	Grams dry wt.	47	279	706	1683	3088	4271	6691
	Gms. N	.45	3.33	6.24	12.22	19.23	21.09	24.16
	Gms. P_2O_5 ...	.29	1.55	3.27	7.27	10.63	12.35	15.97
	Gms. K_2O ...	.94	6,03	13.67	24.15	20.22	18.17	19.93

TABLE VII

SUMMARY OF YIELDS AND ANALYSES OF SERIES IV—PLANTED AUG. 15

(Averages of 3 Replicates at Each Harvest)

Harvested	Leaf-stage Date Age (weeks)	6th Oct. 7 7	12th Nov. 18 13	18th Dec. 26 19	24th Feb. 13 26	30th Apr. 8 33	36th May 16 39	42nd Jun. 30 45	48th Aug. 15 52
Above-ground parts (tops, cane and trash)	Grams dry wt.	28	199	495	1123	2113	2924	4113	4811
	% N	1.83	1.39	1.03	.84	.58	.57	.45	.38
	% P_2O_5	.69	.55	.48	.46	.27	.26	.27	.25
	% K_2O	3.07	2.79	2.23	1.80	1.46	.91	.59	.49
	Gms. N	.51	2.77	5.10	9.43	12.26	16.67	18.51	18.28
	Gms. P_2O_5 ...	.19	1.09	2.38	5.17	5.71	7.60	11.11	12.03
	Gms. K_2O	.86	5.55	11.04	20.21	30.85	26.61	24.27	23.57
Below-ground parts (roots, stubble, and seed piece)	Grams dry wt.	48	69	119	226	339	400	526	762
	% N	.71	.81	.68	.66	.62	.64	.56	.53
	% P_2O_5	.53	.40	.28	.26	.27	.26	.26	.25
	% K_2O	1.30	1.14	.89	.73	.39	.36	.32	.26
	Gms. N	.34	.56	.81	1.49	2.10	2.56	2.95	4.04
	Gms. P_2O_5 ...	.25	.28	.33	.59	.92	1.04	1.37	1.91
	Gms. K_2O	.62	.79	1.06	1.65	1.32	1.44	1.68	1.98
Totals (entire crop)	Grams dry wt.	76	268	614	1349	2452	3324	4639	5573
	Gms. N	.85	3.33	5.91	10.92	14.36	19.23	21.46	22.32
	Gms. P_2O_5 ...	.44	1.37	2.71	5.76	6.63	8.64	12.48	13.94
	Gms. K_2O	1.48	6.34	12.10	21.86	32.17	28.05	25.95	25.55

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1943, TO DECEMBER 15, 1943

Date	Per Pound	Per Ton	Remarks
Sept. 16 - Dec. 15, 1943	3.74¢	$74.80	Philippines